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JANUARY 1956 VOL. LI. NO. 1

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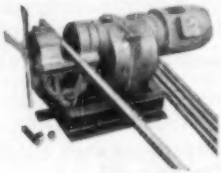

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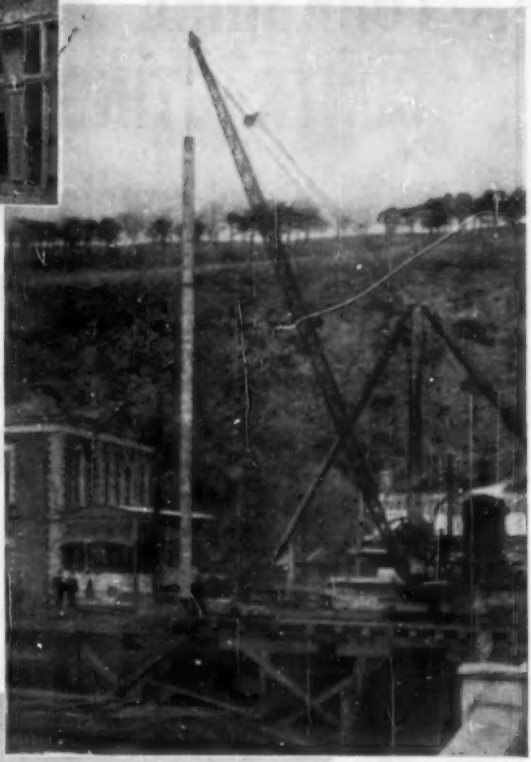
See also pages vii and viii.

CONTRACTS CARRIED OUT BY US IN 1905



Top illustration shows the first reinforced concrete warehouse in this country, which was constructed by us for Rowntree, Ltd. The illustration to the right shows concrete piling work carried out by us at Waterford North Viaduct. The bottom illustration shows extensions at Princes Dock Quay, Liverpool. These three contracts were carried out by us more than 50 years ago.

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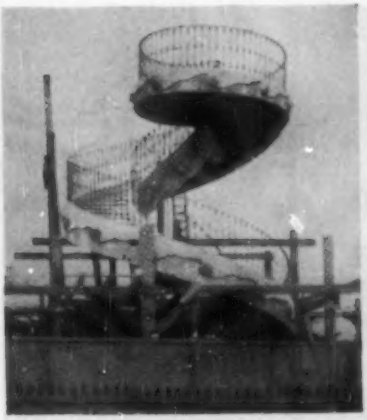

AN EARLY EXAMPLE OF A SPIRAL STAIRCASE CONSTRUCTED IN REINFORCED CONCRETE

The Spiral staircase illustrated above was built by us at the Franco-British Exhibition in 1908. Some of our recent contracts include a reinforced concrete bridge constructed by us for the Huddersfield Corporation (illustrated above), and reinforced concrete barley silos and maltings at South Milford, shown in the bottom illustration.

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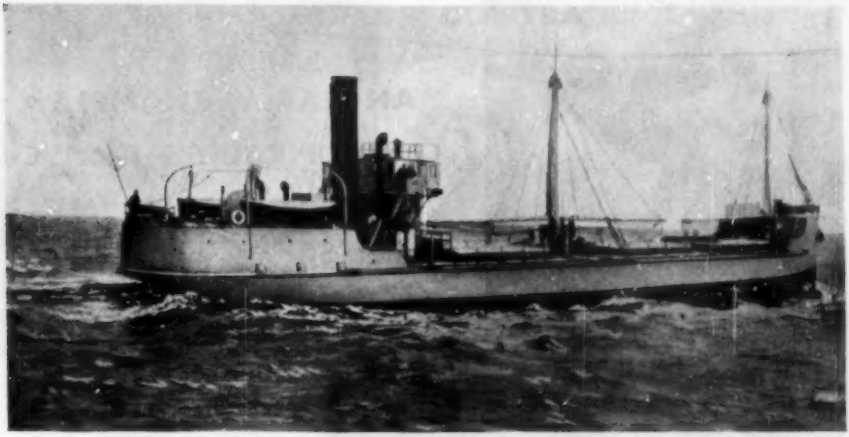
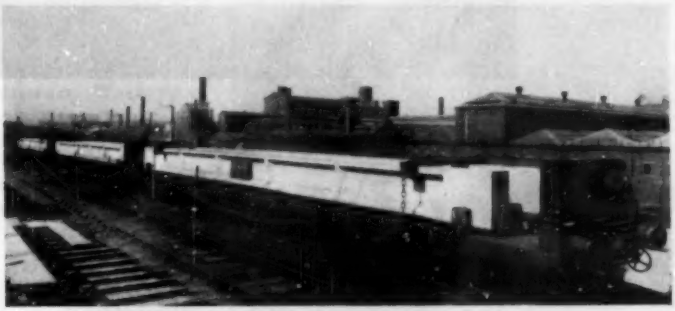
See also pages v and viii.

See also pages v to vii.



A unique example of reinforced concrete work. Ferro-Concrete Ship S.S. Armistice on Steam Trial, 1919. Naval Architects: Messrs. Vickers Limited.



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Expamet

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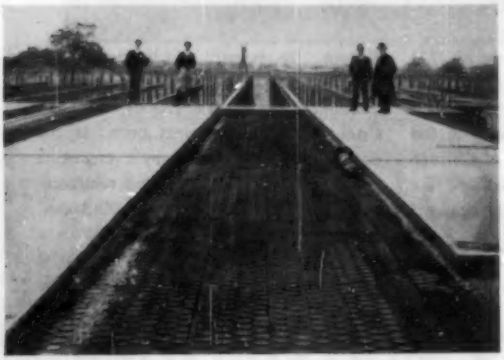
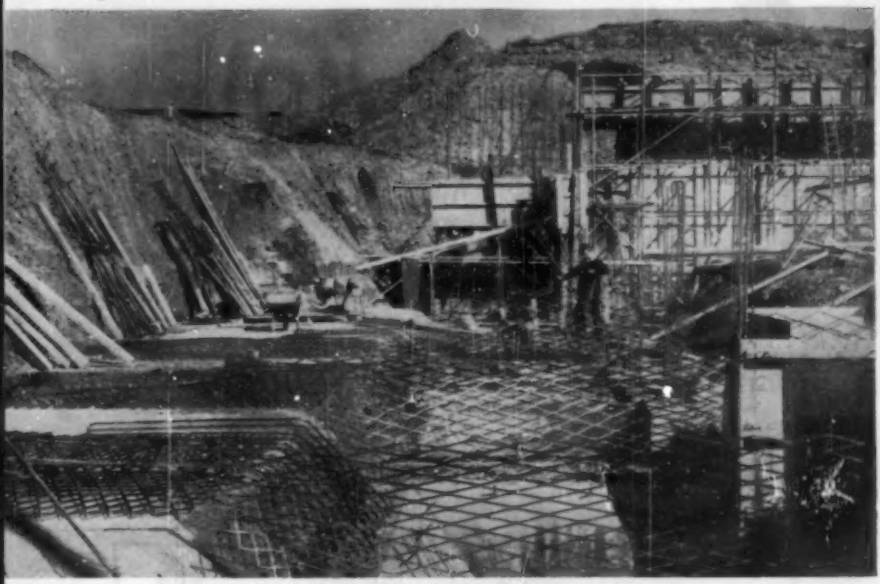
A Half-



An early example of the use of 'Expamet' Expanded Steel as reinforcement for Concrete was in the construction of reservoirs. The illustration shows the construction of the "Expamet" Steel-Concrete cover for a service reservoir at Ipswich, and was taken about 1906.



4½" mesh reinforcement in hoppers of coalbunkers at new factory for Associated Weavers Ltd., Toftshaw, Bradford, Yorks.

Century of Expansion

THIS picture story briefly shows how 'Expamet' has played and is playing its part in civil and structural engineering. It covers half a century—fifty years during which activities in these fields have been faithfully recorded by "Concrete and Constructional Engineering" which is now proudly celebrating its own Golden Jubilee.

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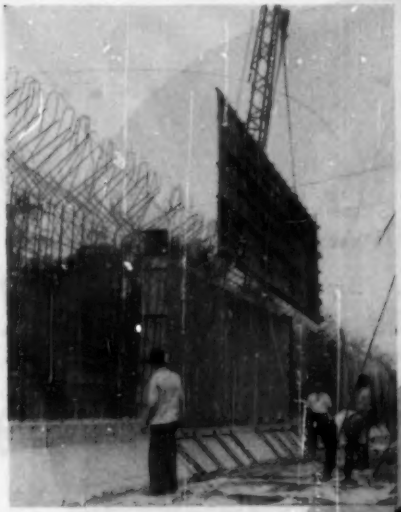

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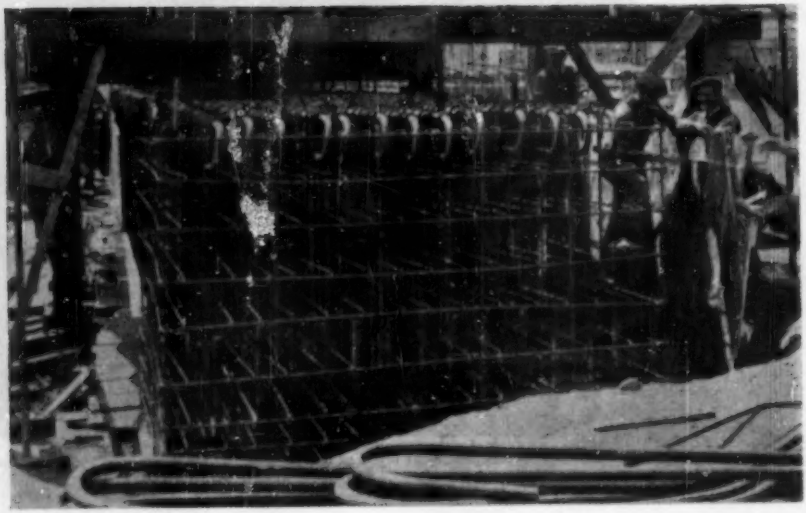

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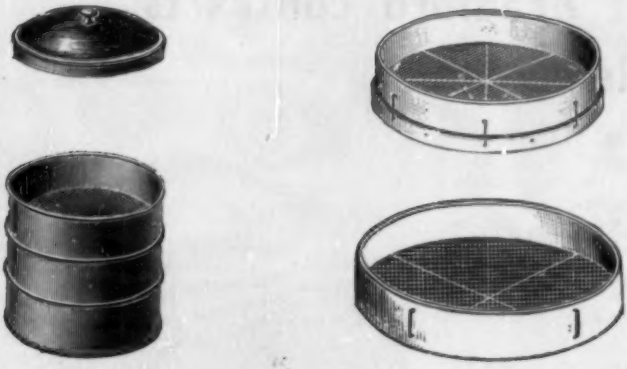

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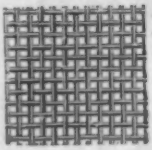

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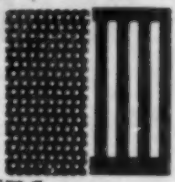

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F. W. Potter & Soar Ltd.

have, from the same address, been suppliers of

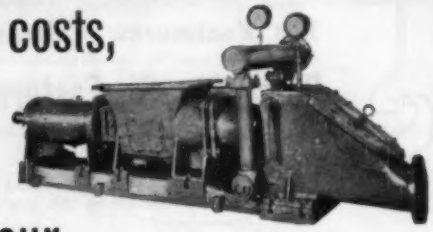
Testing Sieves and Screens for the Cement & Concrete Industries

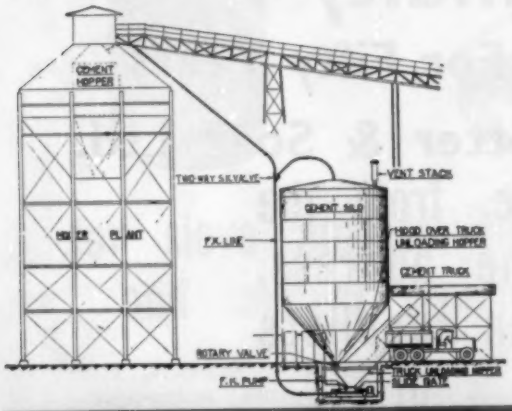
convey BULK CEMENT pneumatically with

FULLER-KINYON

CONVEYING SYSTEM AND F.H. AIRSLIDES

for reduced cement costs, easier handling and storing, and for saving time and labour





This conveying equipment for handling bulk cement is specially designed for rapid and easy erection and dismantling on the site and for the highest efficiency with low working and maintenance costs. Its use in most countries of the world has proved it to be a first-class investment for obtaining the fullest economy in the use of cement for civil engineering and public works contracts of all kinds. Write to the address below for information on how the Fuller-Kinyon pneumatic conveying system can solve your problem and save you money.

CONSTANTIN (ENGINEERS) LTD.

123 VICTORIA STREET, LONDON, S.W.1. Telephone: TATE GALLERY 8637

(Sole licensees for the manufacture and sale of Fuller equipment in Great Britain)

Fifty Years of Progress in Reinforced Concrete Construction

NOW, AS IN THE PAST

CUBITTS

BUILD FOR THE FUTURE

A selection of our contracts showing the progress in reinforced concrete is illustrated on the following pages.

BIRMINGHAM TELEGRAPH STORES. *An early contract of ours in reinforced concrete, The Telegraph Stores at Birmingham, constructed for H.M. Office of Works in 1906.*

CUNARD BUILDING, LIVERPOOL. *The Cunard building started just before the First World War was one of the first entirely reinforced concrete buildings to be erected in England.*

NORTHOLT RACE STAND. *Designed by Dr. Oscar Faber, this stand was erected between 1930 and 1935. The main feature of interest is that the roof, being carried on cantilevers, gives an uninterrupted view.*

19

Among many
but not illustra

Distillery for M
Midland Bank,
Factory for Col
Dam and Wate
Apprentices Tr
L.M. Region).
I.C.I. (Alkalis)
Dock and Jet
Richardson Ltd.
Koepe Windin
Upper Glendev
Rebuilding of
Two schools, a

EMPIRE FLOUR
built by us in 19
high and with an
in 6½ days, and

to 1956

contracts, largely of concrete structure, can be listed the following :—

Tanqueray Gordon & Co. Ltd., E.C.1.
Office, E.C.2.
Ltd., Bristol.
rks, Prewley, Devon.
School, Crewe, (British Railways —

, Holford, Cheshire.
Messrs. Swan Hunter & Wigham
lsend-on-Tyne.
ers, Rothes Colliery, East Fife.
m, Fifeshire.
f Castries, British West Indies.
al and other buildings, Kuwait.

s. The Empire Flour Mills, illustrated above, nsisted of 60 reinforced concrete bins, each 88 ft. l diameter of 16 ft. 32 of these bins were erected ½ days.

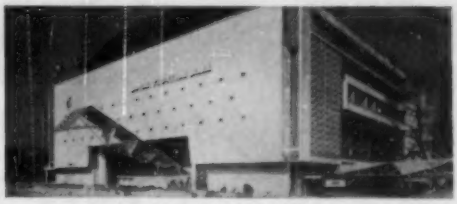
· WESTMINSTER · S.W.1.

Foremost in developing new techniques in concrete constructional engineering, Cubitts were responsible for introducing to this country, Foam Slag, light-weight aggregates, buildings in cellular construction and the Hoyer method of prestressed concrete.

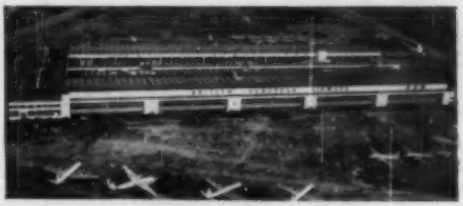
Phoenix Units for Mulberry Harbour

L.C.C. Flats, Bethnal Green

Judas Gap Tidal Barrage



Royal Festival Hall



B.E.A. Hangars, London Airport

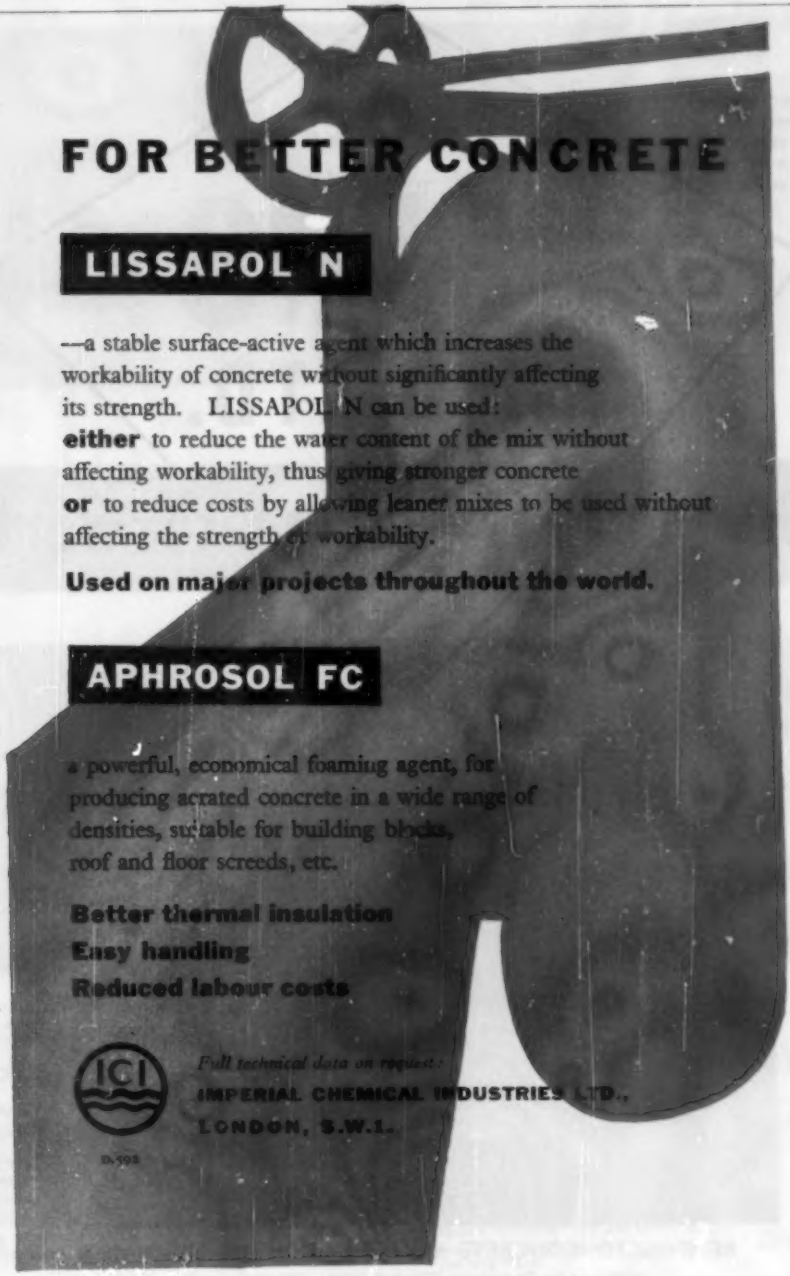
The Roxburgh Hydro Electric Project on the River Clutha in Central Otago, New Zealand, in an advanced stage of construction. The dam when completed will be 1,200 ft. long and will rise 200 ft. above the river bed—the largest project of its kind in the Dominion. The station is designed to feed 320,000 kilowatts into the South Island grid system.

The contractors are Holland & Hannen and Cubitts (New Zealand) Ltd., Conrad Zschokke Ltd., Geneva, and Downer & Co. Ltd., Wellington, working together under the title Cubitt Zschokke Downer.

NOW, AS IN THE PAST

CUBITTS

BUILD FOR THE FUTURE



FOR BETTER CONCRETE

LISSAPOL N

—a stable surface-active agent which increases the workability of concrete without significantly affecting its strength. LISSAPOL N can be used:
either to reduce the water content of the mix without affecting workability, thus giving stronger concrete
or to reduce costs by allowing leaner mixes to be used without affecting the strength or workability.

Used on major projects throughout the world.

APHROSOL FC

a powerful, economical foaming agent, for producing aerated concrete in a wide range of densities, suitable for building blocks, roof and floor screeds, etc.

Better thermal insulation
Easy handling
Reduced labour costs

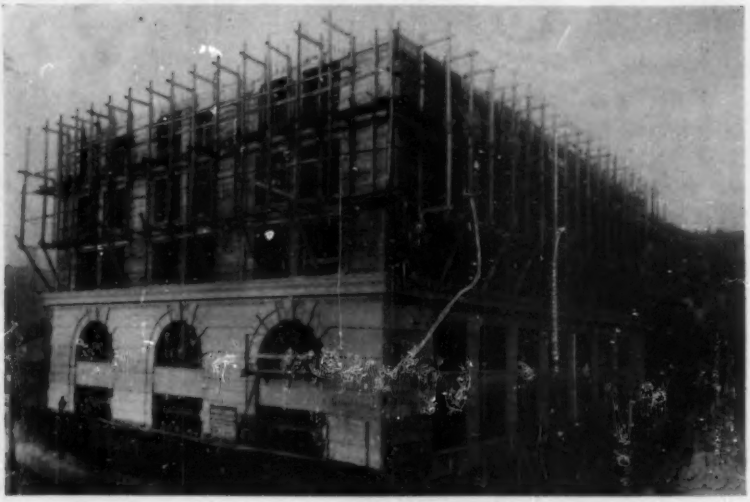
ICI

Full technical data on request:
IMPERIAL CHEMICAL INDUSTRIES LTD.,
LONDON, S.W.1.

D.503

BRIMS
& CO LTD.

50 years of concrete work



REINFORCED CONCRETE CONSTRUCTION BY US IN **1900**

Warehouse for Co-operative Wholesale Society, Newcastle-upon-Tyne.

CONSTRUCTED IN 1937

Deep-Water Quay on reinforced concrete piles 90 ft. long, being an extension of the Tyne Commission Quay built by us in 1928.

in the North of England

12-million gallons storage reservoir at Easington, Co. Durham, constructed by us in 1938 alongside exactly similar reservoir built by us in 1925.

Recently completed Dock extensions for the Middle Docks & Engineering Co. Ltd., South Shields.

OUR LIST OF CURRENT CONTRACTS ALSO INCLUDES—

WM. DOXFORD & SONS LTD.	Shipyard reconstruction and Engine Works development.
CLARKE CHAPMAN & CO. LTD.	Works extensions, including construction of new Fabrication Shops.
TYNEMOUTH CORPORATION	Reconstruction of Fish Quay.
SMITH'S DOCK CO. LTD.	Construction of Deepwater Quay.
MIDDLE DOCKS & ENGINEERING CO. LTD. ..	Reconstruction of Deepwater Quay.
CONSETT IRON CO. LTD.	Demolition of Riverside Quay and Staiths.
J. L. THOMPSON & SONS LTD.	Extension of Crane Track and Crane Gantry.
IMPERIAL CHEMICAL INDUSTRIES LTD. ..	Construction of Reinforced Concrete Tanks for Dust-Handling Plant.
SIR JAMES LAING & SONS, LTD.	Construction of New Crane Track.

PANDON BUILDINGS, NEWCASTLE-UPON-TYNE.

50 years of concrete work

THOMAS VALE & SONS LTD

REINFORCED CONCRETE • IN SITU AND PRECAST ON SITE

Some of the outstanding contracts carried out by us include

INDUSTRIAL STRUCTURES. One of the first completely precast framed factories—1919. The first R.C. Dyehouse in Europe—1931.

RESERVOIRS. Up to five million gallons capacity. At Wolverhampton, Bournemouth, Barnet, Oxford, etc.

GASHOLDER TANKS. In R.C. and mass concrete, amongst the largest in the country.

GRAIN SILOS. For the Ministry of Works. Completed in record time.

BRIDGES. In R.C. for many authorities.

SPECIALISTS. In the design and construction of water-retaining structures, such as Dorr-Oliver Clariflocculators.

THOMAS VALE & SONS LTD

CIVIL ENGINEERING CONTRACTORS

STOURPORT-ON-SEVERN, WORCS. *TELEPHONE : 62-4*

Half a century of concrete progress

CONGRATULATIONS

to "Concrete & Constructional Engineering" and to all those who have contributed in any way to this memorable achievement.

★

ROM RIVER

reinforcement service

design · supply . bending . fixing

THE ROM RIVER COMPANY LIMITED

ST. RICHARDS HOUSE, 90 EVERSHOLT STREET, LONDON, N.W.1

TELEPHONE: EUSTON 7814–9 GRAMS: ROMRIVER, NORWEST, LONDON

Investigation of weighbatching . . .

Provides positive proof of all that has been claimed for this modern method of concrete mixing. Weighbatching yields consistent quality—nullifies bulking—eliminates variations in proportioning . . .

a Big step forward from hit-or-miss shovel loading !

Weighbatching is the simplest method of overcoming variation in sand content due to the bulking of moisture-laden sand.

Road Machines were the first in this country, and probably in the world, to manufacture and sell these smaller types of Weighbatching Equipment on a large scale.

According to many eminent practical Engineers, Weighbatching is the largest single factor in securing good quality control of concrete production.

Weighbatching saves labour at the mixer and by maintaining consistent quality concrete reduces time and labour in placing.

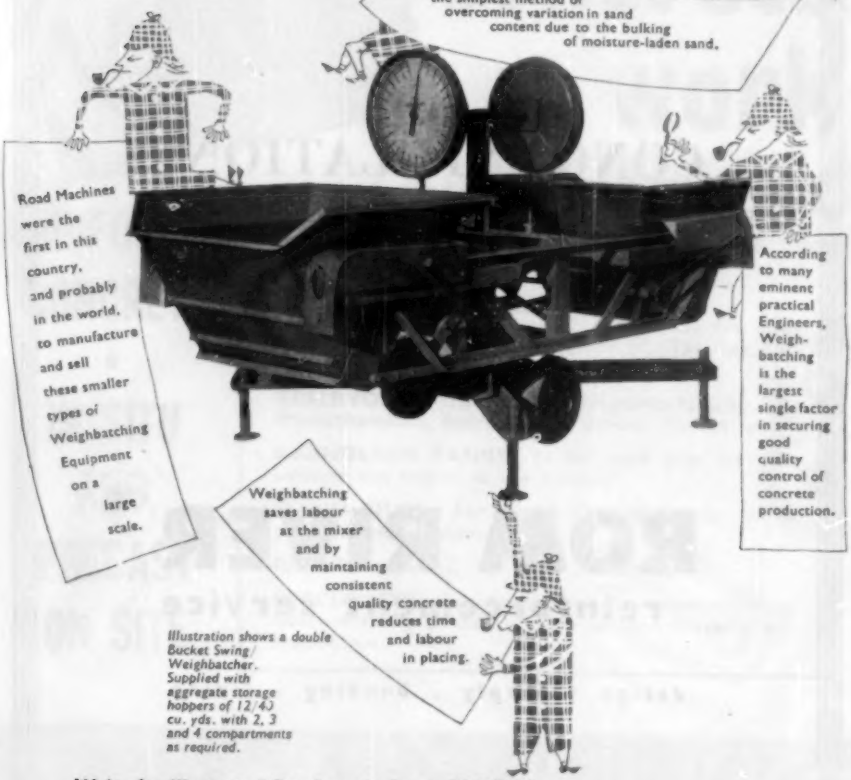


Illustration shows a double Bucket Swing Weighbatcher. Supplied with aggregate storage hoppers of 12/40 cu. yds. with 2, 3 and 4 compartments as required.

Write for illustrated Brochure to Dept. (C.C.E.I.)

ROAD MACHINES (DRAYTON) LTD.

West Drayton. Middlesex.

Telephone : West Drayton 3221-2-3.
Telegrams : Roadmach, West Drayton.
Manufactured by the makers of the "Drayton Dumper" and the "Mono-Rail Transporter".

ROAD MACHINES PRODUCT

L7840A

HISTORICAL HYPOTHESIS NUMBER 2

John Loudon MacAdam

got below

the surface

of things

...*by realizing the importance of a hard, long wearing surface for the roads of his day if they were to cope effectively with the ever growing volume of traffic*

How glad he would have been to use present day concrete cured with SISALKRAFT Blankets. Their toughness and ease of handling simplify and speed up road making, a safeguard against winter frosts and assured curing in summer heat.

He would have marvelled, too, at the strength of Subsoil grade SISALKRAFT which takes such good care of the underside of concrete, reducing sub-grade friction, ensuring maximum strength and protection from impurities.

SISALKRAFT

Estd. 1857

J.H.SANKEY & SON.LTD ALDWYCH HOUSE, ALDWYCH, LONDON, W.C.2

Sole Distributors for British Sisalkraft Ltd. *Phone:* HOLborn 6949 (20 lines) *Grams:* Brickwork, Estrand, London.

C/AD

Colcrete
COLLOIDAL CONCRETE

ADEN PORT DEVELOPMENT

CONSULTING ENGINEERS : SIR BRUCE WHITE, WOLFE BARRY & PARTNERS, LONDON.

CONTRACTORS : PAULING & CO. LTD. LONDON.

CELLULAR WALL
830ft. long

Unreinforced Block and Tee Units precast by grouting, with air and material temperatures around 100° F., preplaced aggregate from central grout mixing plant with Colgrout consisting of :

Cement : 1 part by weight.
Fly Ash : 0·25 part by weight
Sand : 2·45 parts by weight.
Water : 1·02 parts by weight

Works cube tests 1900 p.s.i. at 28 days.

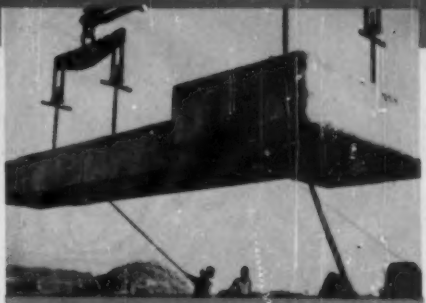
Tee unit for grouting.

Centrally-disposed Colcrete Mixers and Pumps.

Contract includes 1348 ft. of mass wall grouted in situ under water.

PRECAST MARINE CONSTRUCTION

One end of Precasting Yard.



Lifting 21-ton Tee unit 57 ft. long.

Placing 10 ft. × 6 ft. Deck Block.

Positioned Units with Grouted Joints.

COLCRETE LIMITED

GUN LANE
STROOD
KENT

TEL.: STROOD 7334 & 7736.
TELEGRAMS: "GROUTCRETE", ROCHESTER.

HACKNEY GENERATING STATION FOR B.E.A.
(LONDON DIVISION)

GENERAL CONTRACTORS

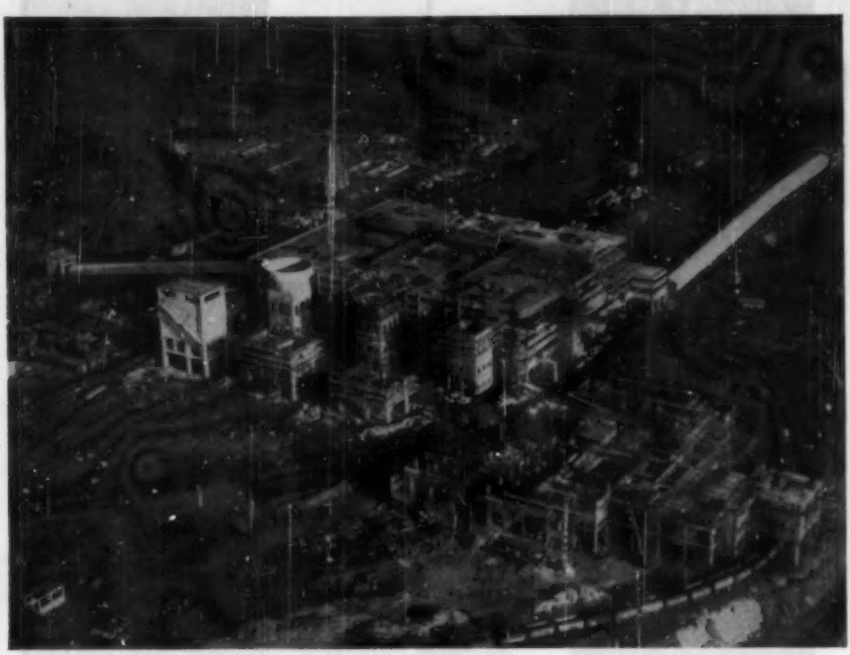
FOR PILED FOUNDATIONS, TURBINE HOUSE, PRECIPITATOR HOUSE, PRESTRESSED BRIDGE, CHIMNEY, WHARF, ROADWORK AND BOUNDARY WALL,

CONSULTING CIVIL ENGINEERS:
L. G. MOUCHEL & PARTNERS LTD.

J. L. KIER & Co. LTD.

CIVIL ENGINEERING CONTRACTORS
7, LYGON PLACE, WESTMINSTER, S.W.1

CENTRAL COAL PREPARATION PLANT—MANVERS MAIN
FOR THE N.E. DIVISION, AREA No. 3—NATIONAL COAL BOARD



MAIN CONTRACTORS FOR

ALL PILE FOUNDATIONS INCLUDING 1500 PILES, CENTRAL COAL WASHERY BUILDING, THREE SETTLING TOWERS, THREE RAW COAL BUNKERS, THREE 60'-0" DIA. THICKENERS, JUNCTION HOUSES, CONVEYOR FOUNDATIONS, SHALE BUNKERS, WAGON TIPPLER STATION, CHIMNEY AND ROADWORKS, ETC.

CONSULTING ENGINEERS:
HUSBAND & CO.

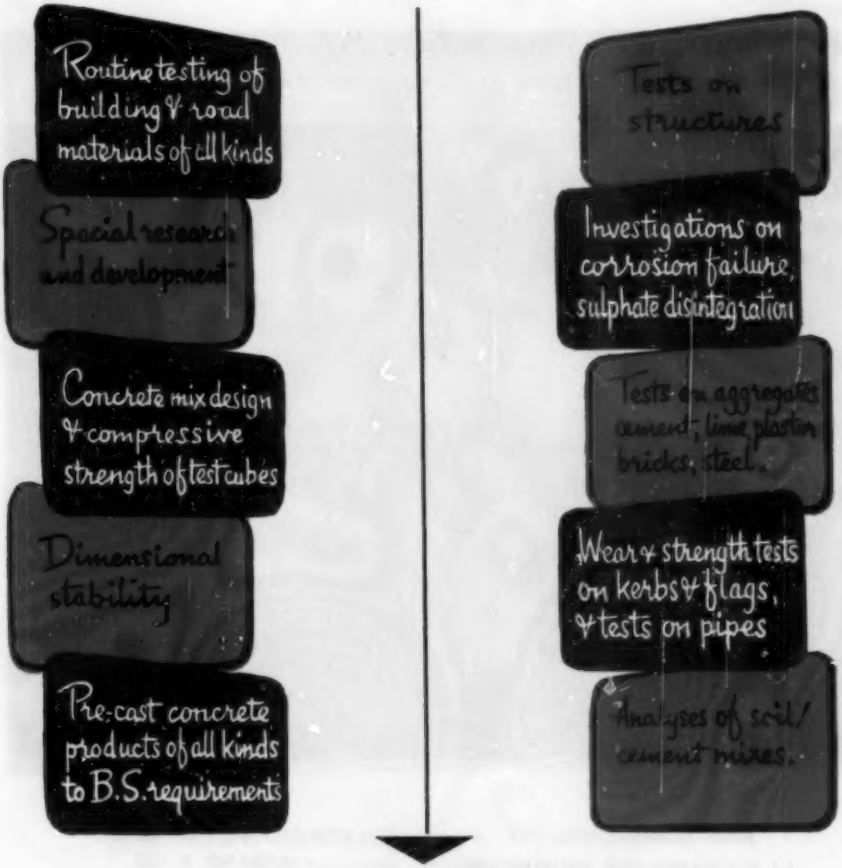
Published by permission of the National Coal Board

Photo by Aero Pictorial Ltd.

J. L. KIER & Co. LTD.

CIVIL ENGINEERING CONTRACTORS

7, LYGON PLACE, WESTMINSTER, S.W.1


Routine testing of building & road materials of all kinds
Special research and development
Concrete mix design & compressive strength of test cubes
Dimensional stability
Pre-cast concrete products of all kinds to B.S. requirements
Tests on structures
Investigations on corrosion failure, sulphate disintegration
Tests on aggregates, cement, lime, plaster, bricks, steel.
Wear & strength tests on kerbs & flags, & tests on pipes
Analyses of soil/cement mixes.

CONSTRUCTIVE ANALYSIS
of concrete and all concreting materials
is readily available at

ELLIS RESEARCH AND TESTING
LABORATORIES
LTD.

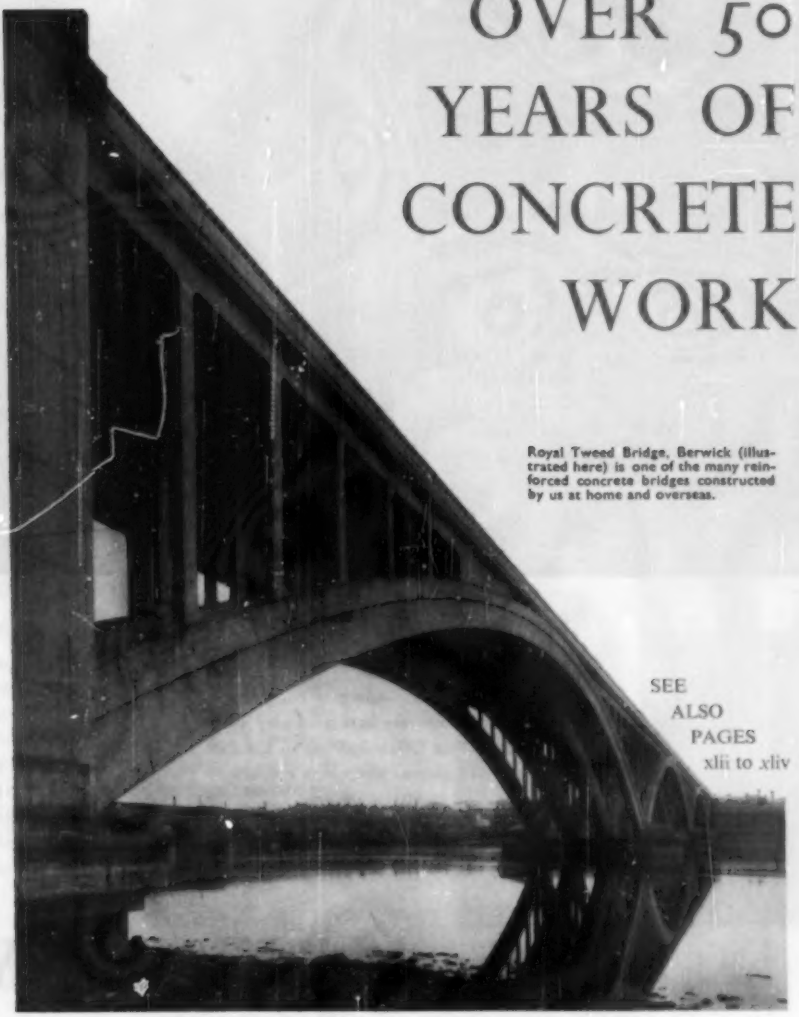
ALBURY · NEAR GUILDFORD · SURREY
Telephone: Shere 341–342, 352

HOLLOWAY BROTHERS

(LONDON) LIMITED

BUILDING AND CIVIL ENGINEERING CONTRACTORS OF MILLBANK, WESTMINSTER

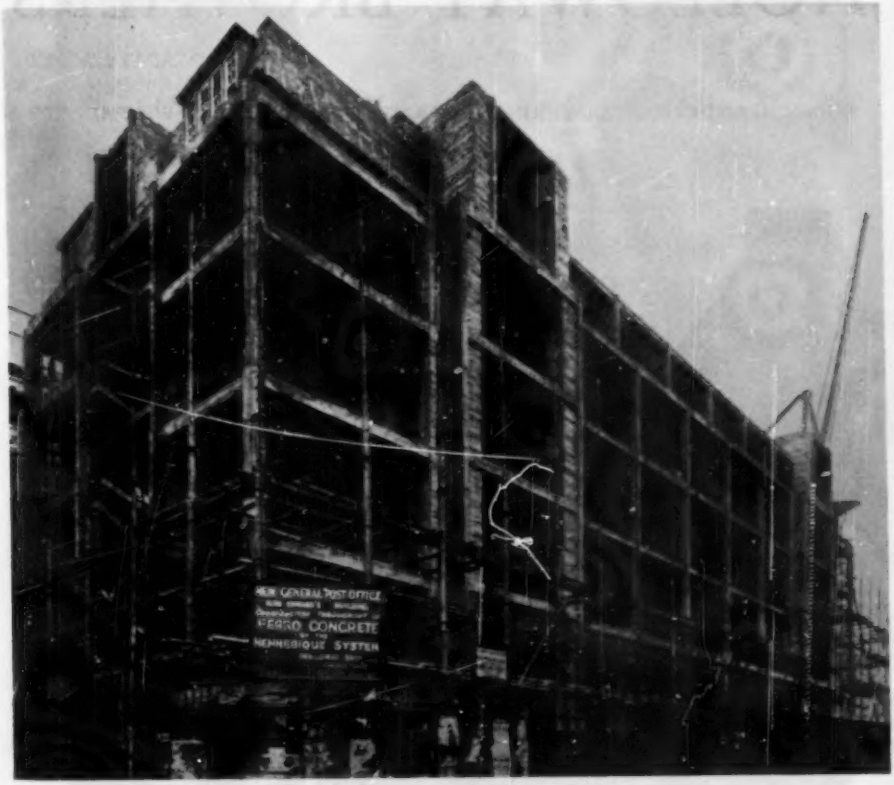
OVER 50 YEARS OF CONCRETE WORK



Royal Tweed Bridge, Berwick (illustrated here) is one of the many reinforced concrete bridges constructed by us at home and overseas.

SEE ALSO PAGES xlii to xliv

(*SEE ALSO PAGES xli and xliv*)

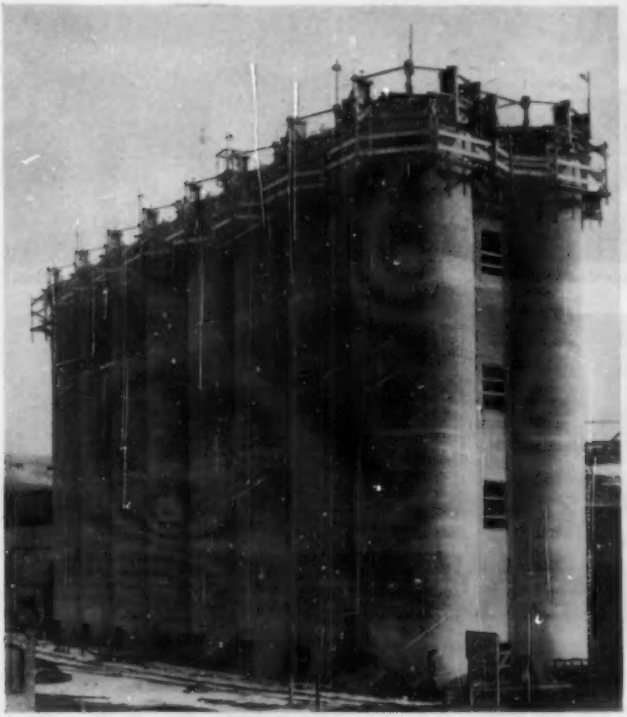


REINFORCED CONCRETE CONSTRUCTION IN 1906

One of the first important contracts in reinforced concrete in this country is the General Post Office Building in London, illustrated above, which was erected by us fifty years ago.

HOLLOWAY

BUILDING AND CIVIL ENGINEERING



SPEEDY CONSTRUCTION IN 1938

These illustrations show a group of 16 reinforced concrete silos, the walls of which were cast in a period of six days ; and a reinforced concrete chimney, 279 feet high, the shaft of which was constructed in less than two months. The stage at which the moving form construction commenced is shown in the illustration on the left of the chimney.

BROTHERS

(LONDON) LIMITED

CONTRACTORS OF WESTMINSTER

(*SEE ALSO PAGES xli to xliii*)

An example of shell roof construction carried out by us for the Crawley Development Corporation.

Reinforced Concrete Coal Bunkers for the North Thames Gas Board.

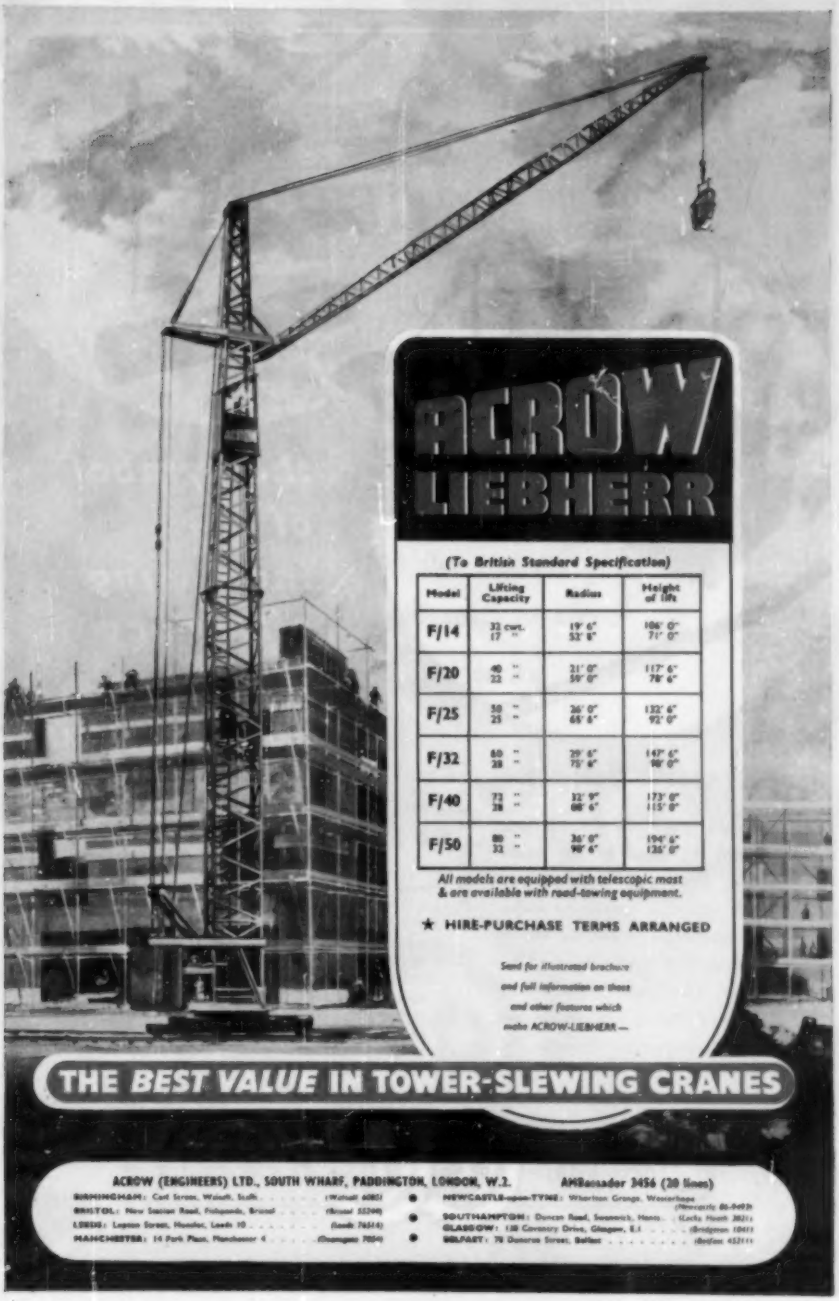
Reinforced Concrete Coal Preparation Plant constructed by us for the National Coal Board at Mardy, South Wales.

RECENT CONTRACTS BY

HOLLOWAY BROTHERS

(LONDON) LIMITED

BUILDING AND CIVIL ENGINEERING CONTRACTORS OF MILLBANK, WESTMINSTER



ACROW LIEBHERR

(To British Standard Specification)

Model	Lifting Capacity	Radius	Height of Lift
F/14	32 cwt. 17 "	19' 6" 53' 6"	106' 0" 71' 0"
F/20	40 " 22 "	21' 0" 59' 0"	117' 6" 78' 6"
F/25	50 " 25 "	26' 0" 65' 6"	132' 6" 92' 0"
F/32	60 " 28 "	29' 6" 75' 6"	147' 6" 98' 0"
F/40	72 " 28 "	32' 9" 68' 6"	173' 0" 115' 0"
F/50	88 " 32 "	36' 0" 90' 6"	194' 6" 126' 0"

All models are equipped with telescopic mast & are available with road-towing equipment.

★ HIRE-PURCHASE TERMS ARRANGED

Send for illustrated brochure and full information on these and other features which make ACROW-LIEBHERR—

THE *BEST VALUE* IN TOWER-SLEWING CRANES

ACROW (ENGINEERS) LTD., SOUTH WHARF, PADDINGTON, LONDON, W.2. AMBassador 3456 (20 lines)

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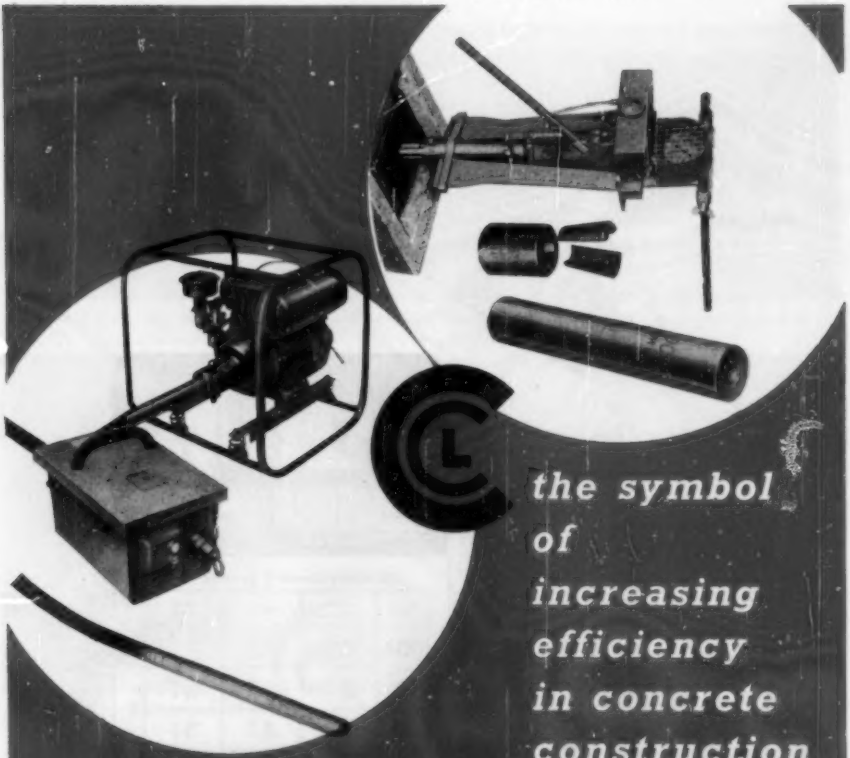
BRISTOL: New Station Road, Filton, Bristol . . . . . (Bristol 52244)
LEEDS: Lagoon Street, Hunslet, Leeds 10 . . . . . (Leeds 76514)
MANCHESTER: 14 Park Place, Manchester 4 . . . . . (Deansgate 7054)
NEWCASTLE-upon-TYNE: Wharton Grange, Wooperhope . . . . . (Prudhoe 66-949)
SOUTHAMPTON: Duncan Road, Swaythling, Hants . . . . . (Locks Heath 3821)
GLASGOW: 130 Cavendish Drive, Glasgow, S.1 . . . . . (Bridgeton 1041)
BELFAST: 79 Donegall Street, Belfast . . . . . (Belfast 452111)



the symbol of increasing efficiency in concrete construction

Immersion Vibrators

Here are the most powerful and efficient Vibrators in the world today. Ultra-high frequency of 17,000 vibrations per minute and a 1¼" diameter poker head that allows accessibility without damage to the moulds. The flexible drive has a slow speed shaft of 2,800 r.p.m., and can be interchanged between the electric and petrol models.

The Advantages of the Gifford-Udall-CCL Prestressing System

For the Contractor:

1. Speed and simplicity of operation.
2. Light, compact and sturdy equipment.
3. Positive mechanical CCL anchorage.
4. Inexpensive equipment.
5. The backing of the CCL service.

For the Designer:

1. Flexibility of design concerning all forms of construction.
2. The obvious design advantages of a single wire system combined with positive and inexpensive mechanical anchorage.

Fullest information, specifications and data will gladly be sent on request

Gifford-Udall-CCL-Tremix

PRESTRESSING SYSTEMS

IMMERSION VIBRATORS

CABLE COVERS LIMITED, Prestressed Concrete Division, St. Stephen's House, Westminster, S.W.1. Tel: Elmbridge 7741-5

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to

"CONCRETE AND CONSTRUCTIONAL ENGINEERING"

on the

achievement of 50 years of service

to Civil Engineering

CONCRETE PILING LTD

10 WESTMINSTER PALACE GARDENS, ARTILLERY ROW,
LONDON, S.W.1. PHONE: ABBEY 1626/7.
LADA DRIVE, BELFAST. PHONE: BELFAST 58100
WORKS: RIVER ROAD, BARKING. PHONE: RIPPLEWAY 2624

Established 1834

WILLIAM

COWLIN

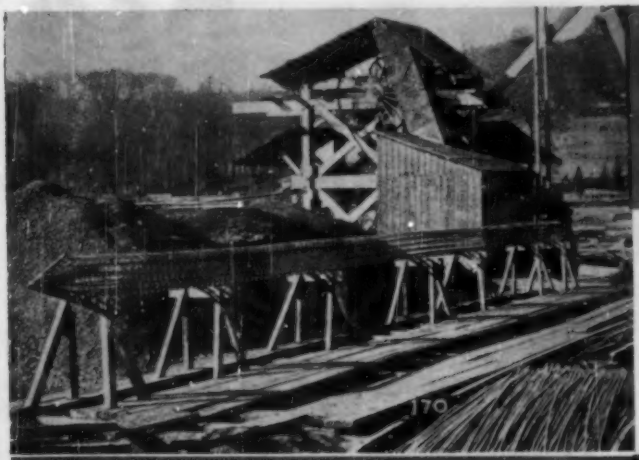
AND SON LIMITED

*

Building Contractors

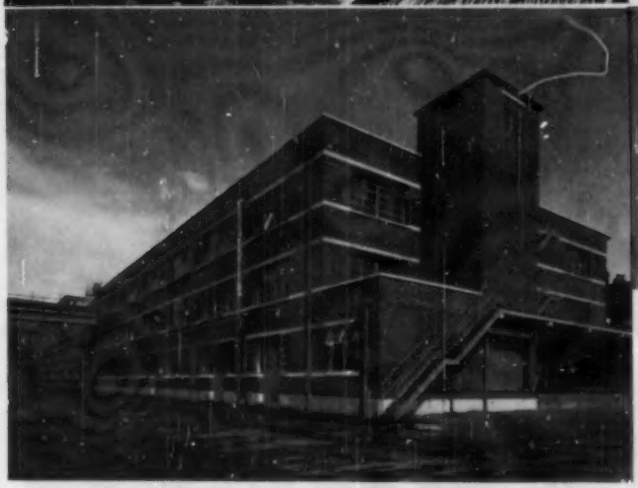
*

The Pioneers of Reinforced Concrete Construction in West of England



CONCRETE PILING IN 1905

One of the earliest concrete piling contracts in this country was carried out by us. The illustration shows one of the piles in course of manufacture at our works for this contract.



REINFORCED CONCRETE CONSTRUCTION IN 1955

Our long experience in reinforced concrete construction includes many important contracts for industrial buildings, reservoirs, bridges, piled foundations, etc. Our list of contracts also includes prestressed concrete construction.

PHOTO BY KIND PERMISSION OF DISTILLERS CO. LTD.

Modern Yeast Factory recently completed by us, involving heavy reinforced and prestressed concrete superstructure construction. Being contiguous to the River Avon, the sub-structure work consisted of reinforced concrete strip foundations, sheet piling, and reinforced concrete load-bearing piles.

WILLIAM COWLIN AND SON LIMITED

HEAD OFFICE AND WORKS: STRATTON STREET, BRISTOL 2

TELEPHONE: 22132 (seven lines) TELEGRAMS: CONSTRUCT, BRISTOL

AND AT

113 CATHEDRAL ROAD, CARDIFF

Telephone: CARDIFF 32736

.... a really BIG time-saver in handling large volumes of concrete

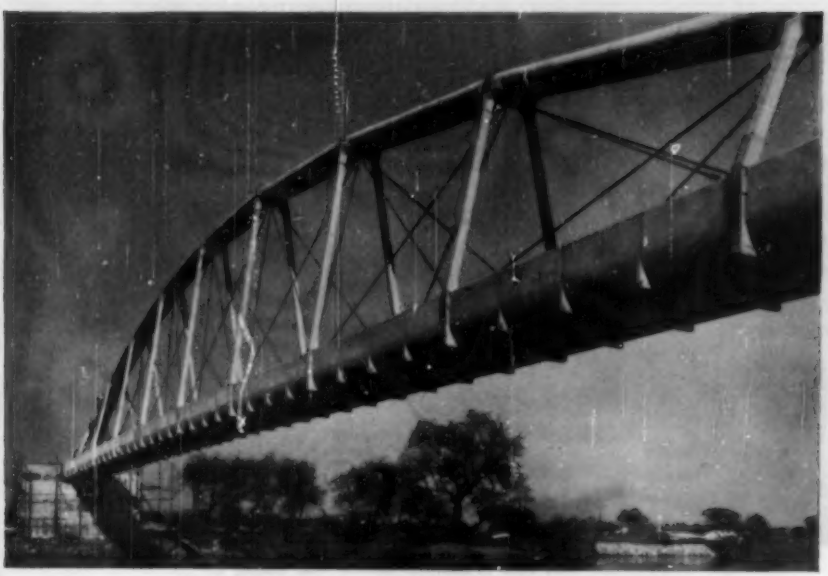
Designed to speed up the construction of concrete roads, runways, and factories where an efficient method of concrete handling and placing is essential.

TELECRETE

A continuous flow of concrete from a central mixing plant can be easily and quickly handled with the "Telecrete". Its specially designed discharge-chute enables concrete to be transported with speed and economy, avoiding costly stoppages on the contract. Sturdily constructed to withstand heavy wear and tear, it is easy to manœuvre on congested sites. Let us send you full details.

TELEHOIST LIMITED : CHELTENHAM

Telephone : Cheltenham 53254-5-6 & 55152



PRESTRESSED CONCRETE PIPE BRIDGE CONSTRUCTED BY

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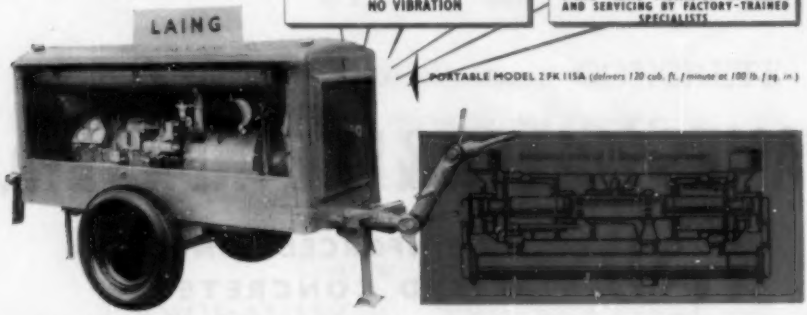

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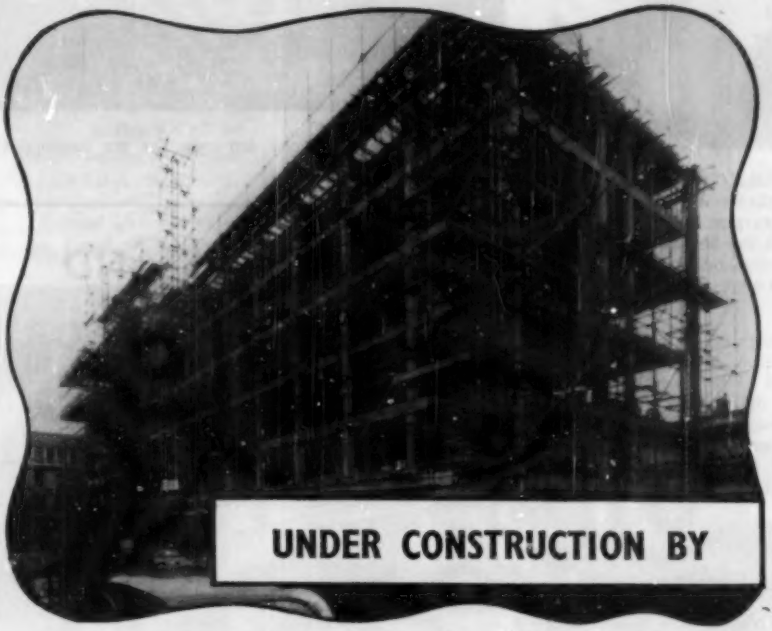

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Landsales bunker, capacity 400 tons, for the National Coal Board, at Bold Colliery.

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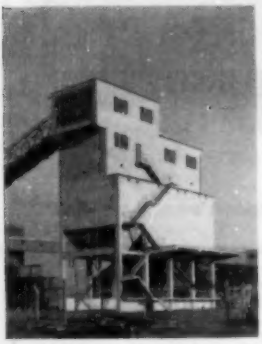
Coal-preparation plant for the National Coal Board at Bank Hall Colliery, Burnley. Left to right: storage bunkers, capacity 380 tons; rail bunkers, capacity 150 tons; and landsales bunkers, capacity 650 tons.



Headgear for National Coal Board at Bold Colliery. Left to right: No. 3 airlock, No. 2 headframe, No. 1 headframe.

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General Contractors :
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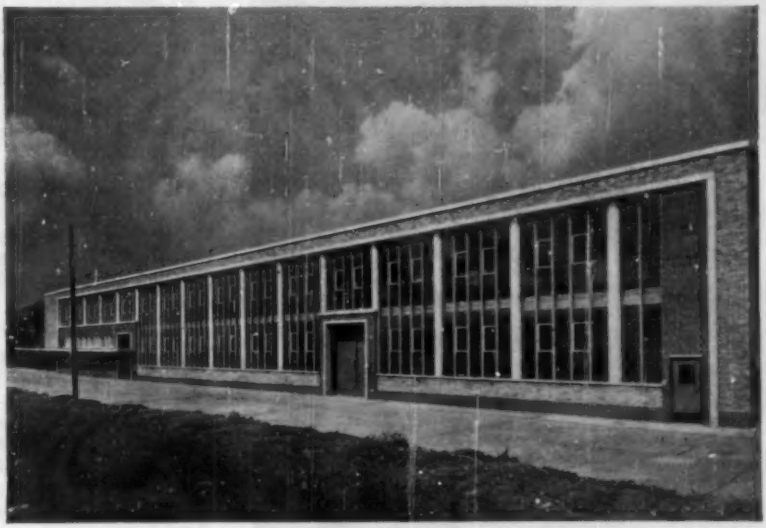

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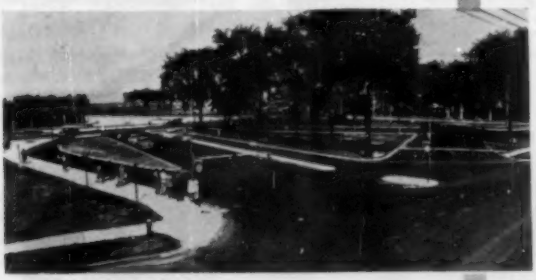

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Above left :—McCalls "MATOBAR" Fabric was used in this traffic "Channelizer" constructed for the Montreal City Planning Dept. (*Photo by "The Gazette", Montreal.*)

Left :—Photo of Digbeth road-widening scheme for Birmingham Corporation, using "MATOBAR" Welded Fabric. City of Birmingham Engineer and Surveyor: Sir Herbert J. Manzoni, C.B.E., M.I.C.E. General Contractors: Tarslag Ltd. (*Photo. by "Birmingham Post".*)

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Above right: Prestressed concrete road overbridge, Takoradi Harbour extensions, Gold Coast. Designed by Rendel, Palmer & Tritton, and constructed by Taylor Woodrow (W. Africa) Ltd., using the Lee-McCall system.

Right:—This South Eastern Gas Board store at Greenwich has precast arch-ribs—Lee-McCall post-tensioned units. Designed by Central Construction Dept., S.E. Gas Board. Contractors: Demolition & Construction Co., Ltd.

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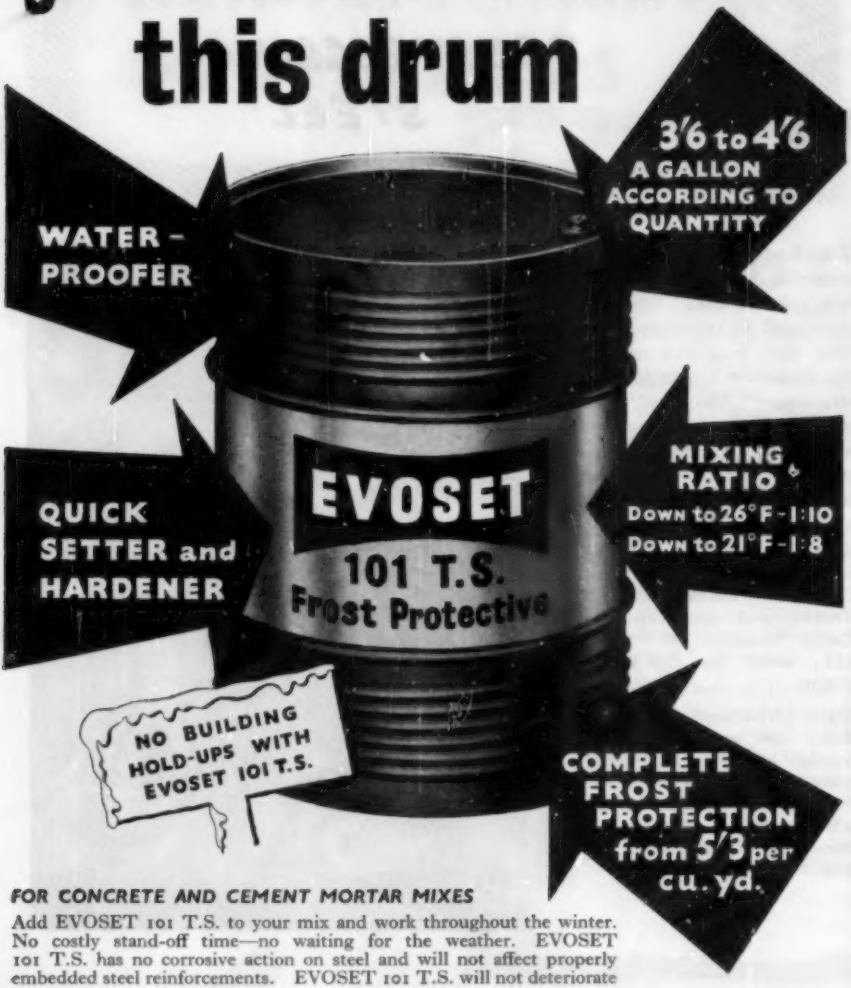
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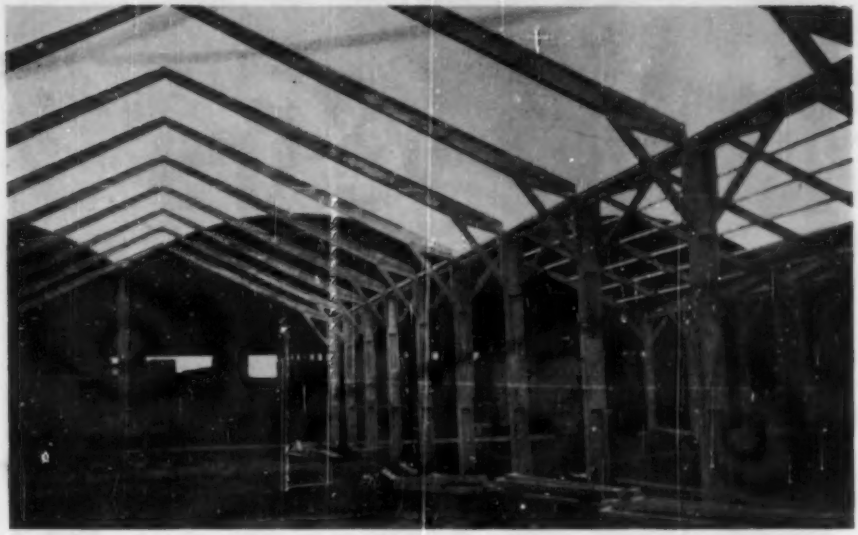

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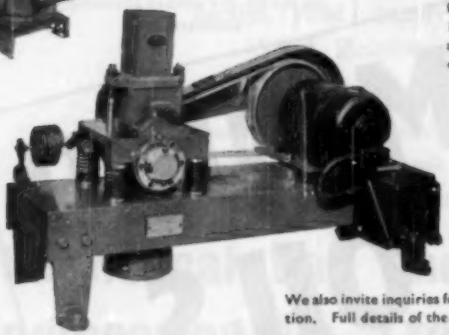

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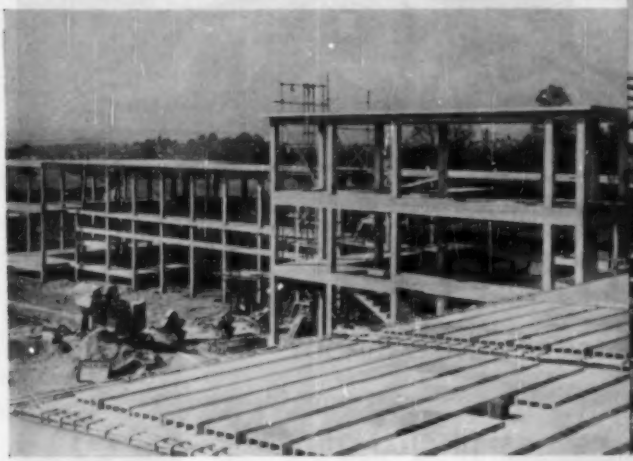

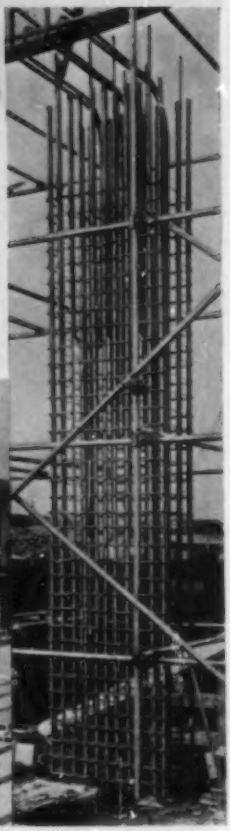

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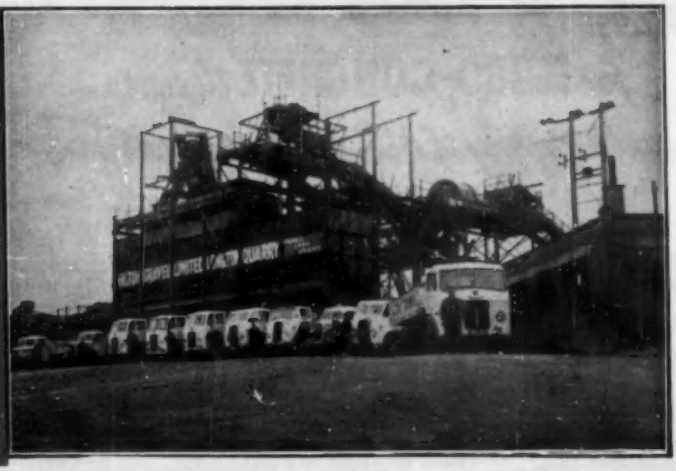

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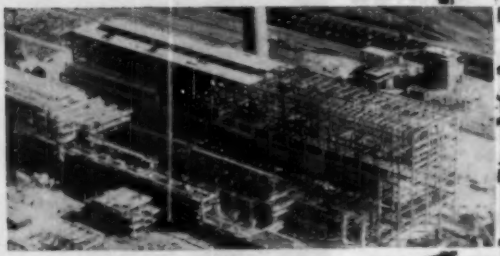

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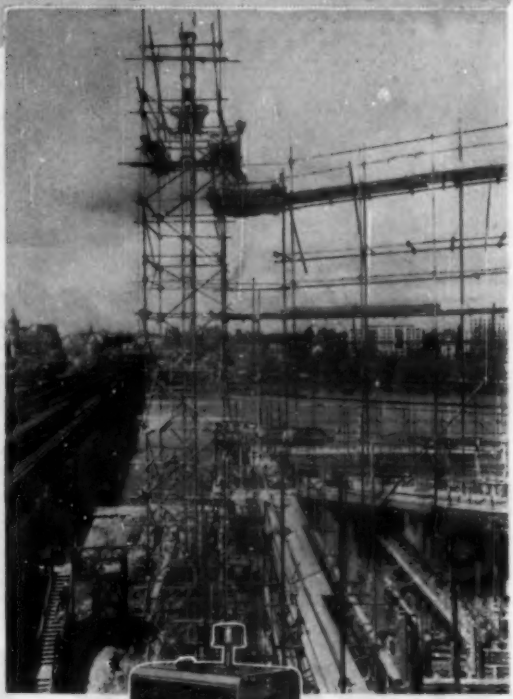

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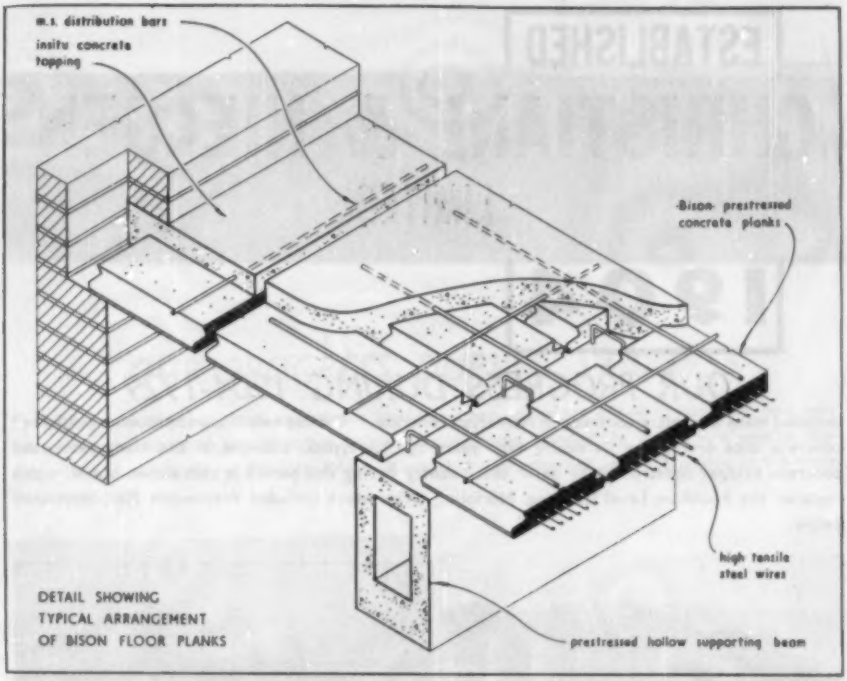

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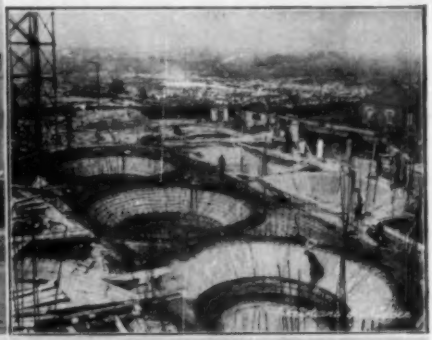

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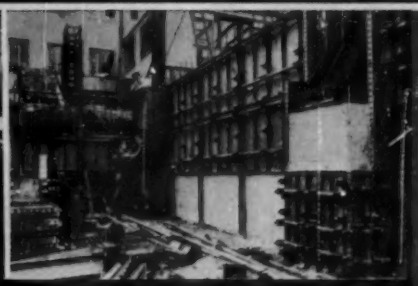

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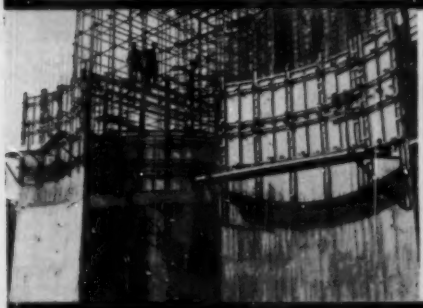

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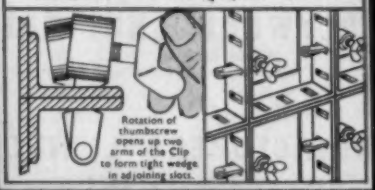
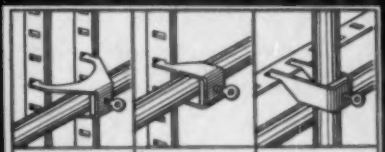
As formwork for a surge shaft, 60ft. diam., 120ft. deep, in Scotland.
Note also Acrow Scaffold Units employed as staging.
Contractors : Messrs. Whetlings Ltd.

The *NEW* ACROW ASSEMBLY CLIP

(Patent applied for) for securing adjacent Wallforms





BRIDGE CLIP (Registered Design)
For connecting scaffold-tube waling to Channel Soldier.

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For connecting scaffold-tube waling to Wallform.

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For connection when scaffold-tube is used for soldiers as well as for walings.

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PARAMOUNT FOR :—

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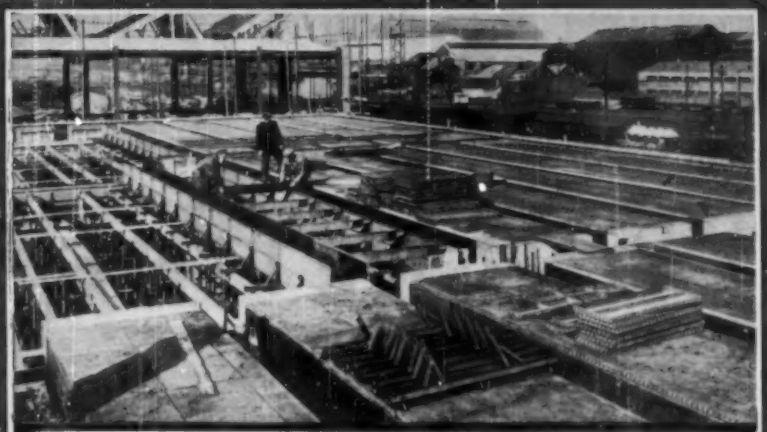

For slab and beam formwork on extensions to cable works for S.A. Ateliers de Constructions Electriques de Charleroi, Belgium. Note also the Acrow Beam Clamps for clamping beam formwork, and the Acrow Floor-centres being placed in position for supporting the slab formwork.

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It is fitted with a large hopper and mechanically operated conveying gear, combined with a feeding box. The gear mechanism is automatically lubricated by an oil bath within the gear box.

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Full specification will be sent on application.

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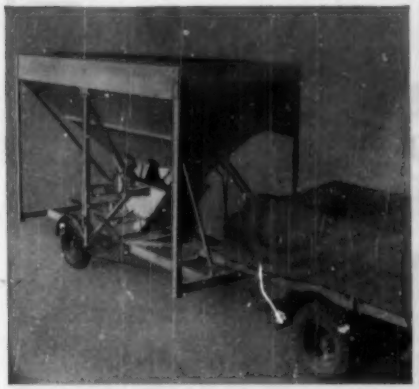
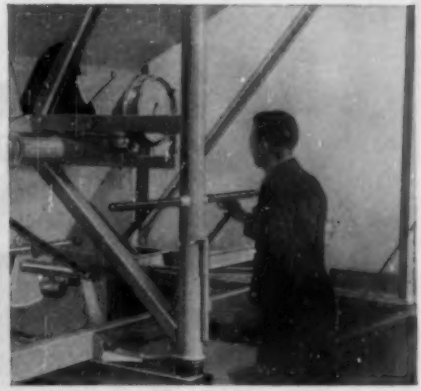
A fully mobile weighbatcher with accurate hydraulic weighing



Towed complete by truck.



Simple accurate hydraulic weighing.

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Loading height is only 10-ft. Aggregates can be supplied to the bin by shovel loader — an excavator is not a necessity. Plant being compactly designed is ideal where street or bank loading of the bin is necessary.
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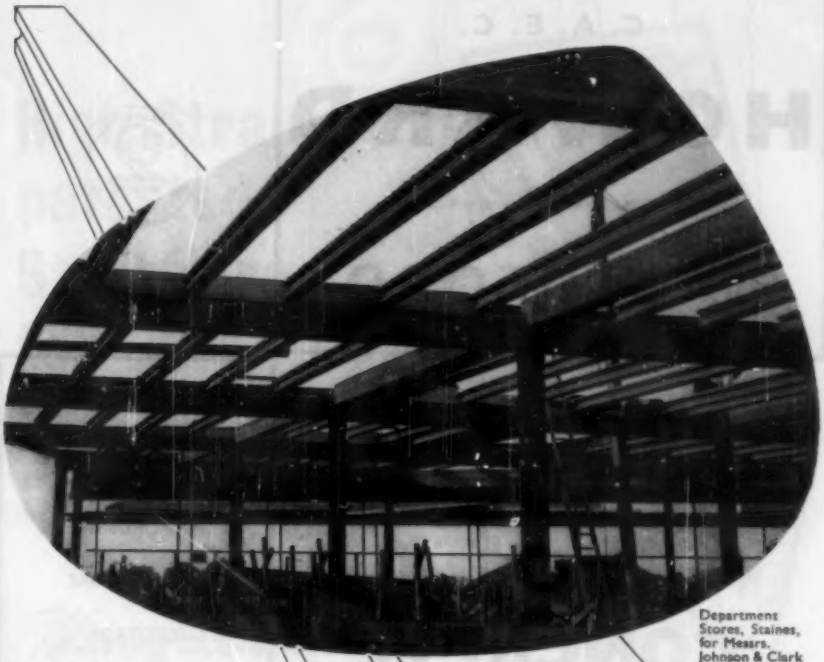

Department Stores, Staines, for Messrs. Johnson & Clark Ltd. Chartered Architects: Messrs. Kimpton & Freeman.

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For the above contract Pierhead Ltd. are carrying out the Composite Prestressed Flooring, the Beam Encasing, Reinforced Stairs, etc., and Prestressed Concrete Roofing.

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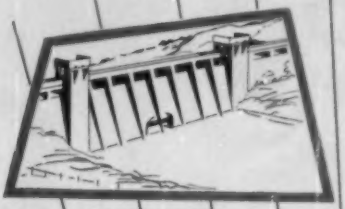

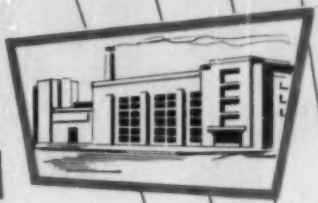

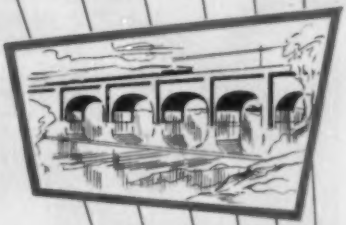

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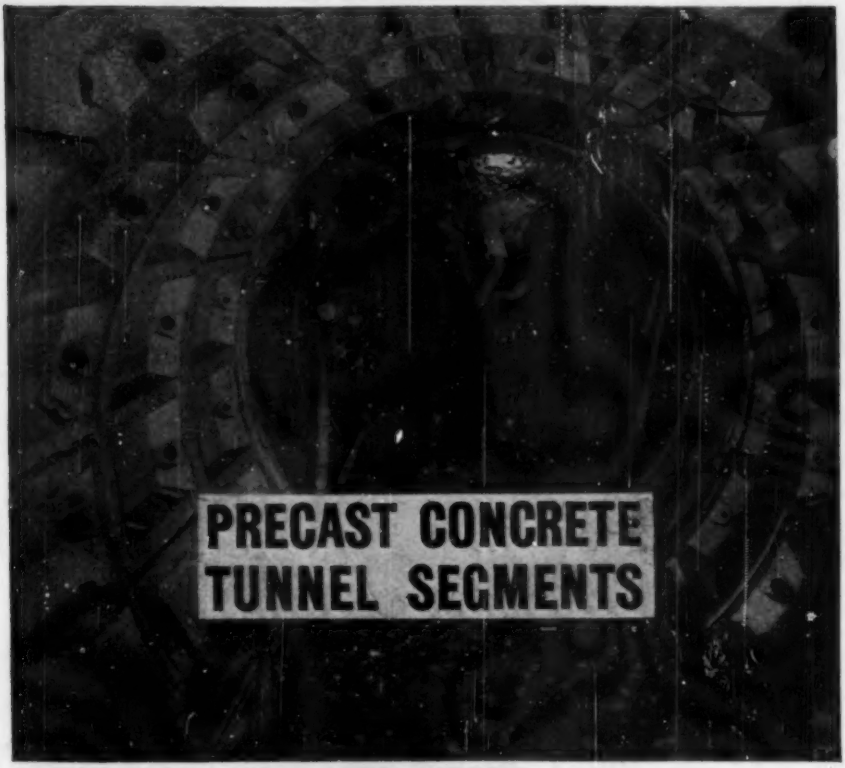

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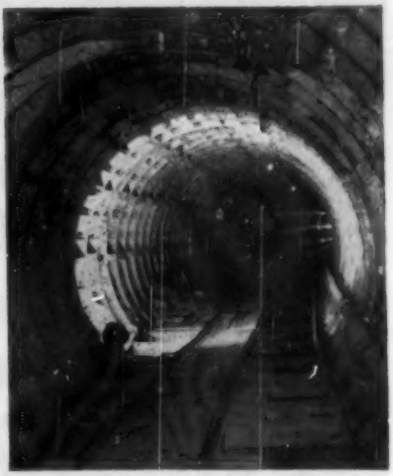
The 9-ft. diameter tunnel for this scheme is 7,868 ft. long, and is lined with SHOCK-CRETE precast concrete segments, each 2 ft. wide and about 5 ft. 3 in. long.



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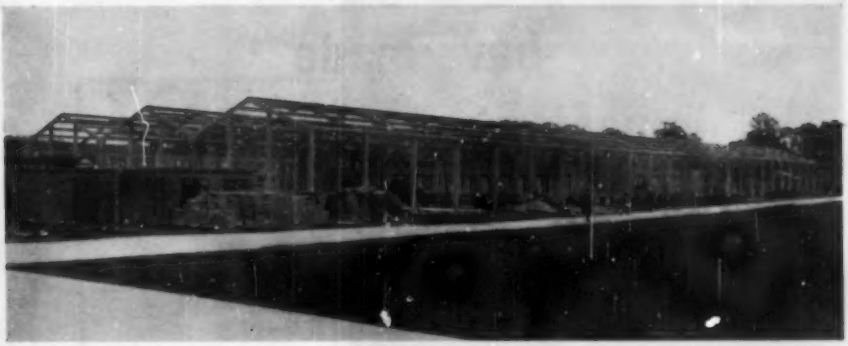

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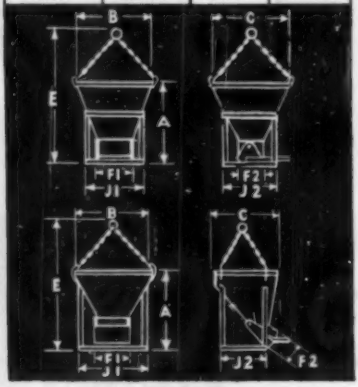
	18	14	9
Height 'A'	3' 9"	Bottom 3' 6" Side 3' 8"	3' 3"
Length 'B'	3' 10"	3' 3"	3' 3"
Width 'C'	3' 10"	3' 3"	2' 5"
Weight 'D'	3½ cwt.	3 cwt.	2 cwt.
Overall Height inc. Chains 'E'	7' 6"	7' 4"	7' 2"
Construction 'H'	⅛" M.S. Plate 2" x 3/16" A/Iron		
Stand 'J1' x 'J2'	2" A/Iron 3' 0" x 2' 8"	2" A/Iron 2' 8" x 2' 4"	2" A/Iron 3' 0" x 2' 2"
'F1' x 'F2'	Discharge Gate		
Bottom	1' 10" x 10"	1' 6" x 11"	1' 5" x 11"
Side	1' 10" x 11"	1' 6" x 8"	1' 6" x 8"
'K'	Price Ex-Works C.W. Chains		
Bottom	£50-0-0	£47-0-0	£35-0-0
Side	£55-0-0	£50-0-0	£37-0-0



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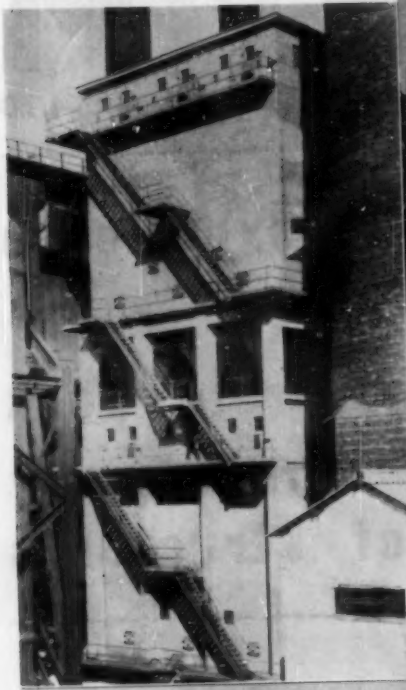

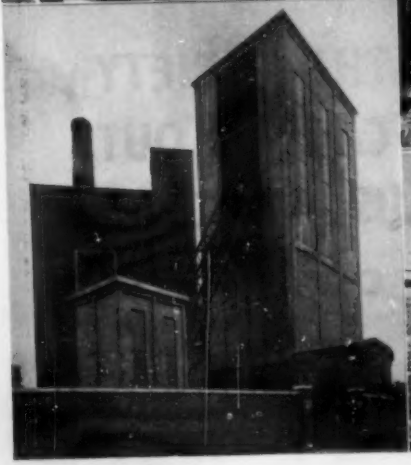

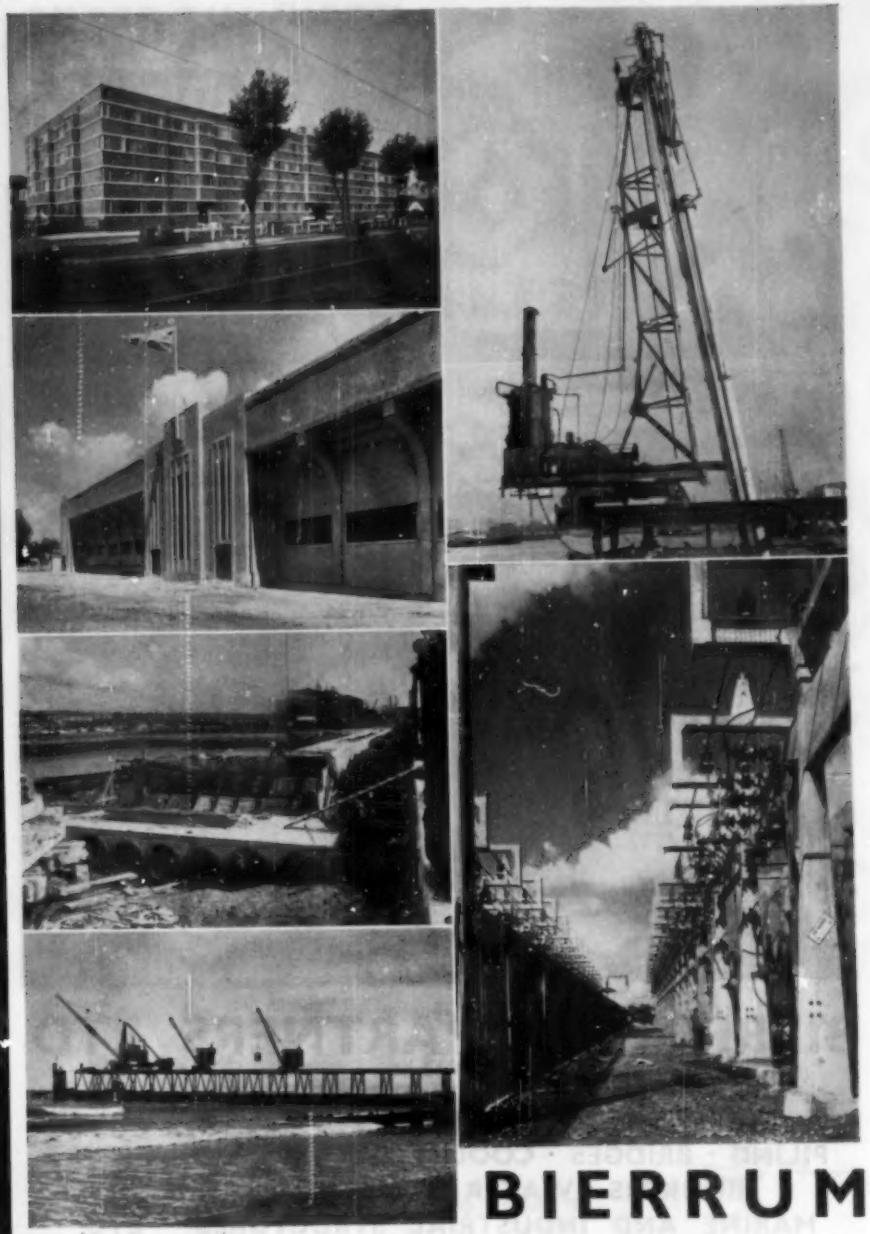

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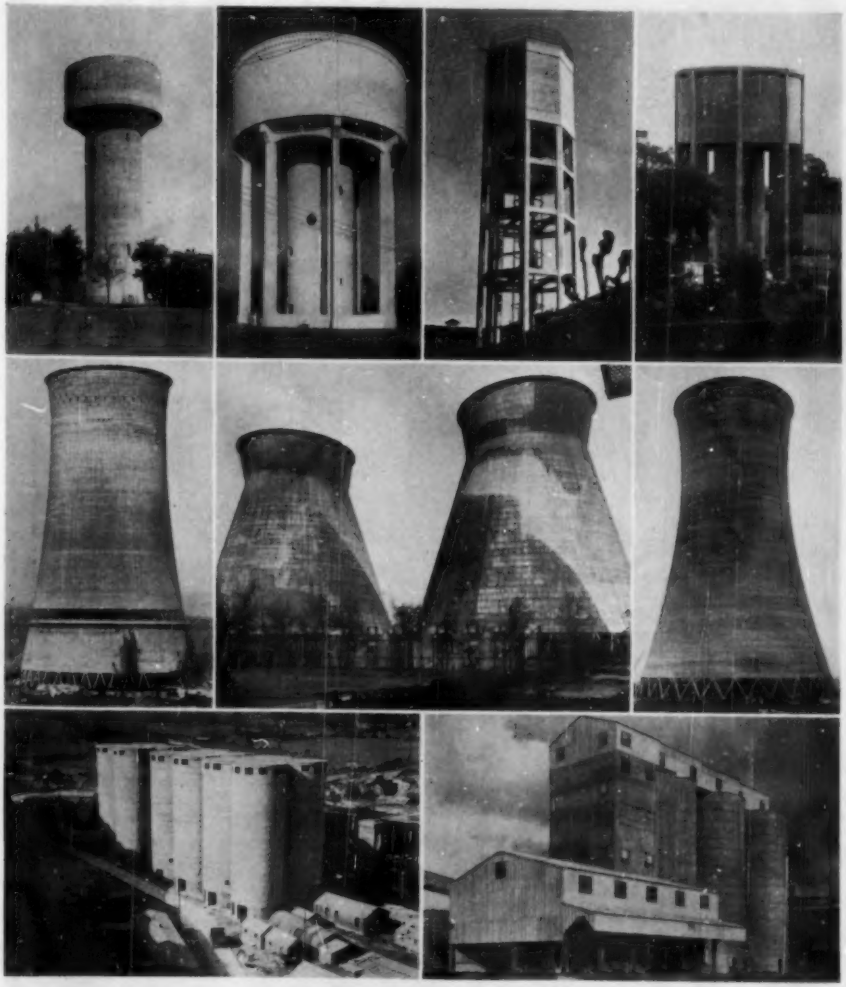

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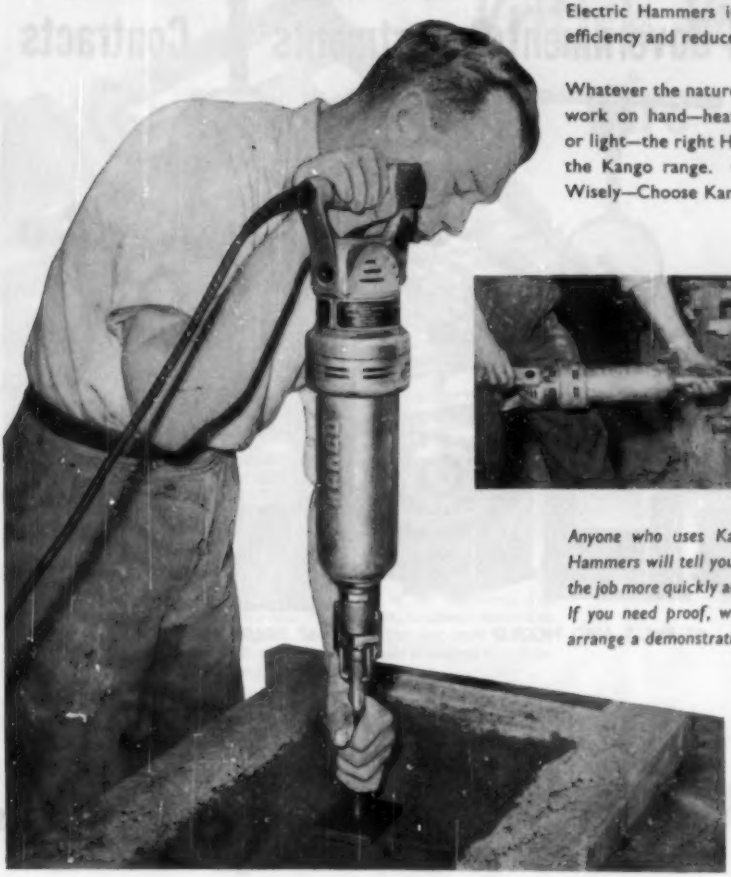

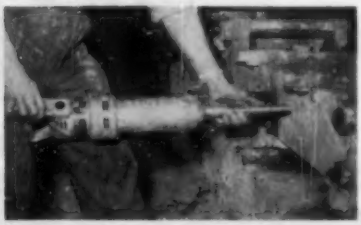

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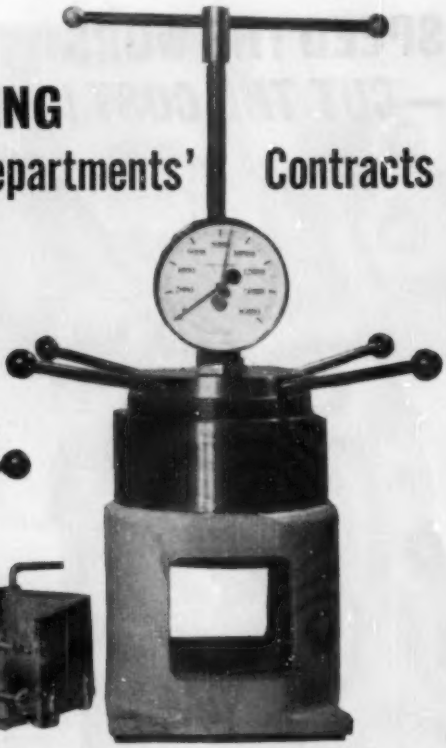

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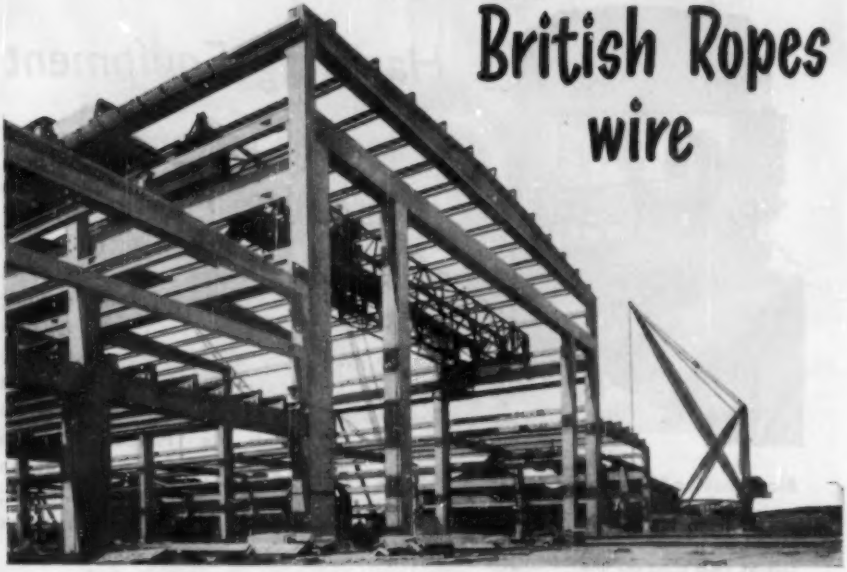
Dowsett chose British Ropes wire



. . . for use in the construction of this engineering shop erected by Dow-Mac (Products) Ltd., for Brooke Marine Ltd. at South Shipyard, Lowestoft. The shop itself is 360 ft. long by 150 ft. wide with a clear height at centre of 41 ft. 6 ins. The structure is entirely of concrete.

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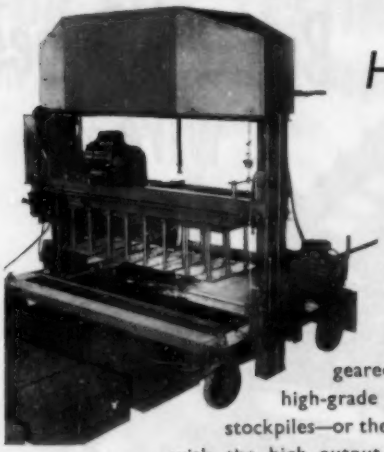
'MULTIBLOC'



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SPEEDS 'THROUGH PUT' and LOADING of BLOCKS

The 'Multibloc' Handling System covers all stages in the manufacture of building blocks from mixing the materials. It is geared to handle the mixed concrete, produce high-grade blocks, and finally dispose of the blocks to stockpiles—or thence to lorries—in an even flow commensurate with the high output of the main unit, the 'Multibloc' Mobile Block-making Machine. There is no breaking of bulk. Mass-produced, the blocks are mass-handled in units of increasing size. This means an enormous saving of labour; four men can remove, stack and load sixty rows of finished blocks in one hour, i.e. as fast as two men on the 'Multibloc' machine are making them.

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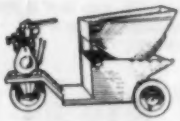

'MULTIBLOC' Aggregate Feed Truck £154

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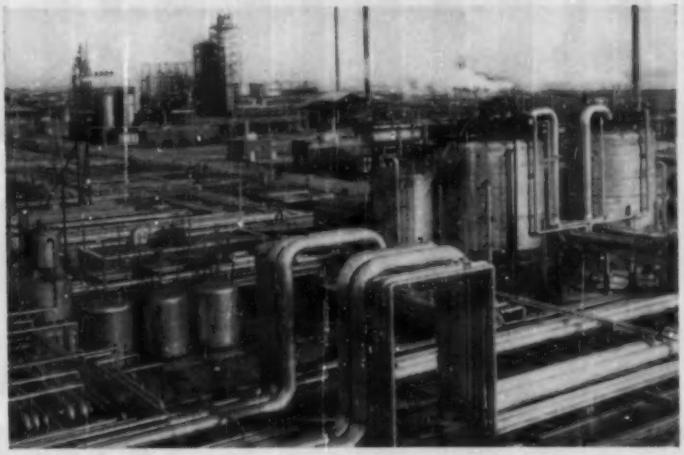
Oil Refineries



Oil Refinery at Coryton

The Coryton refinery of Vacuum Oil Company Limited has been constructed on the waste marshes of Essex, on the north shore of the Thames Estuary 25 miles from London. In her opening address the Queen Mother said that it was hard to imagine that it had been possible in so short a time, to turn what had been marsh land into the throbbing heart of a great industry.

The civil engineering works involved were earth moving and filling operations to raise the level of parts of the site, heavily reinforced concrete foundations and bases, superstructures of reinforced concrete columns and beams to carry the refinery plant, pipe tracks for refinery products and for cooling water, foundations and bases for the huge storage tanks, many miles of drainage, miles of ducts for cables and construction of a power house and sub stations.

A momentous occasion in the civil engineering history of this project was the journey made down Thames by the 4,000 ton reinforced concrete caisson which is now the refinery's water intake works resting on the river bed at Coryton.

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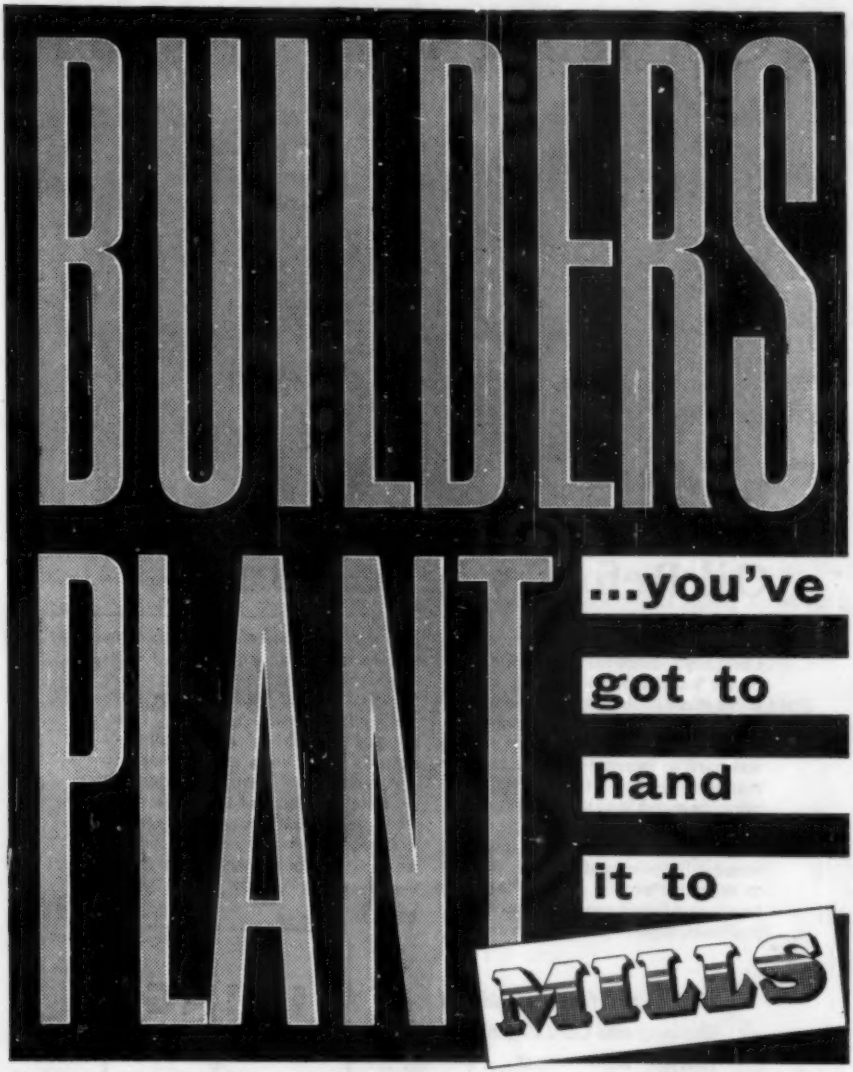

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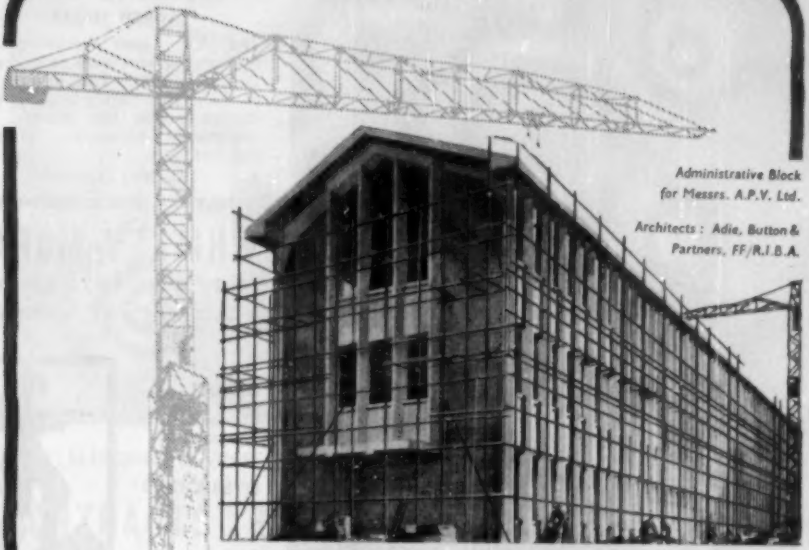

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for Messrs. A.P.V. Ltd.

Architects : Adie, Button & Partners, FF/R.I.B.A.

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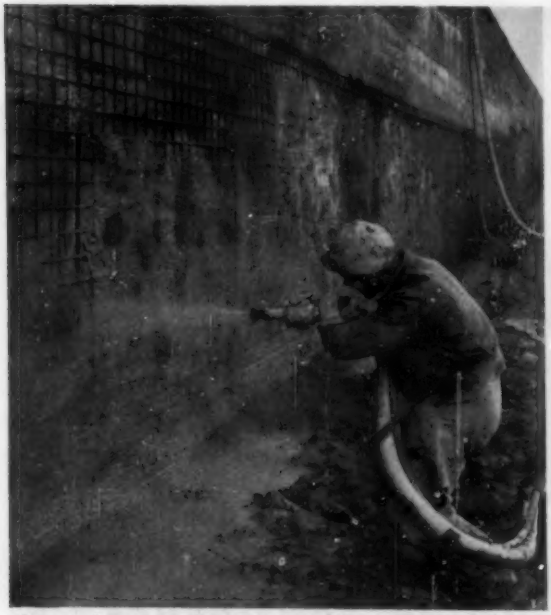

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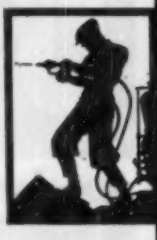

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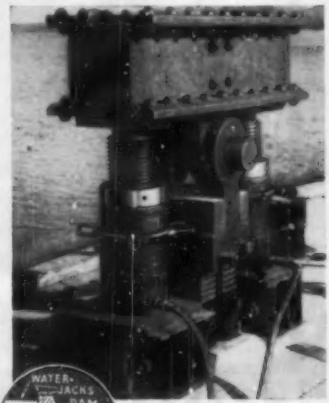
THE CEMENTATION CO., LTD., who have employed the M. André Coyne principle to strengthen the Tansa Dam, near Bombay (see diagram below), chose Tangye hydraulic jacks to impart the necessary pressure of 80 tons on to the top of the dam and on each of the 2,400 cables used along its 2-mile length. There is a Tangye Jack for every need in the higher tonnage range.



Cables pass through drilled holes and are grouted into bed rock. Cables are then subjected to 80 tons stress by means of hydraulic jacks operating between dam and a cross-beam attached to the cable.

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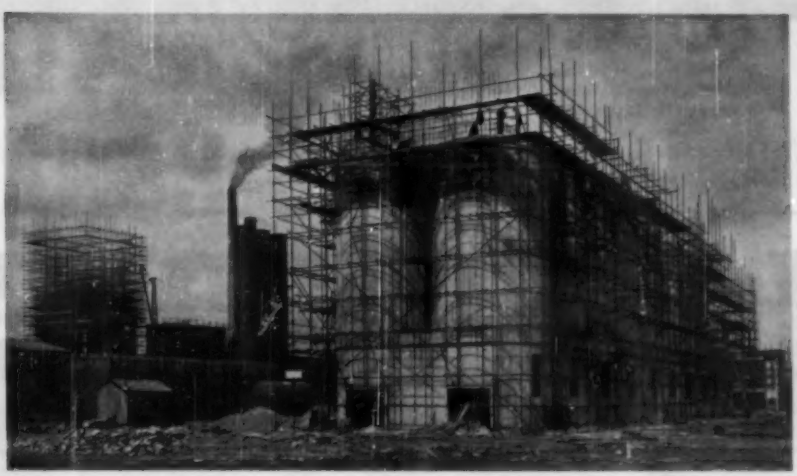

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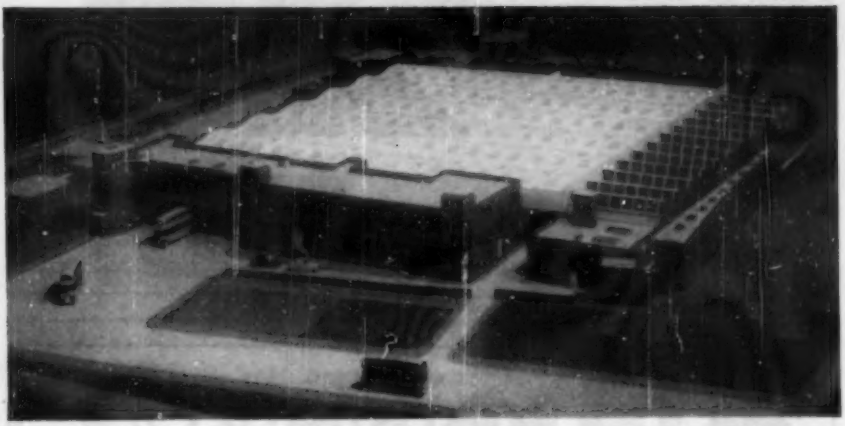

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Ever since prestressed concrete construction was first used in this country, designers, architects and civil engineers have specified "Wire by Johnsons". The reason is quality, built up on early experimental work with those specialist designers who have studied and worked on the Continental development of this new building technique.

Johnsons have a long record of "Firsts", including indented wire for greater bonding and coils of 8 ft. diameter, from which the wire pays out straight.

wire was essential—

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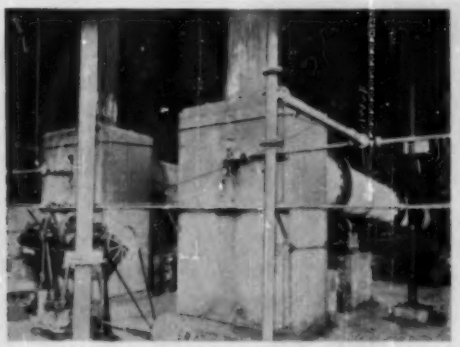

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50 years ago the rotary kiln was an innovation

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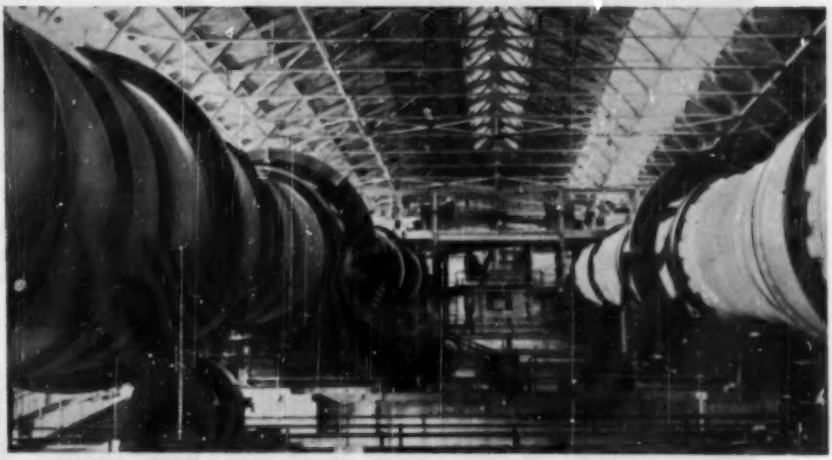
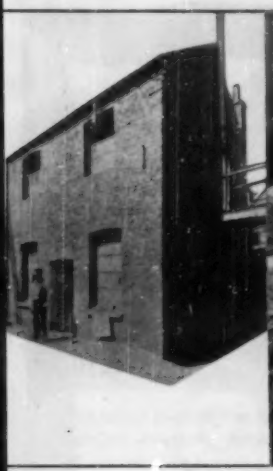


Modern rotary kilns

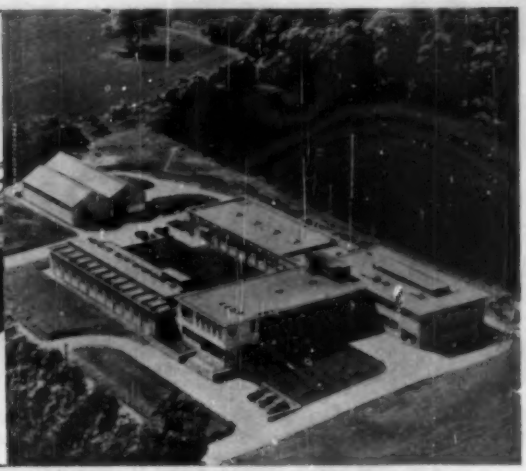
During the past 50 years mechanical plant of advanced design has been introduced in every stage of manufacture to eliminate heavy manual labour, increase output, and reduce costs.

* * * *

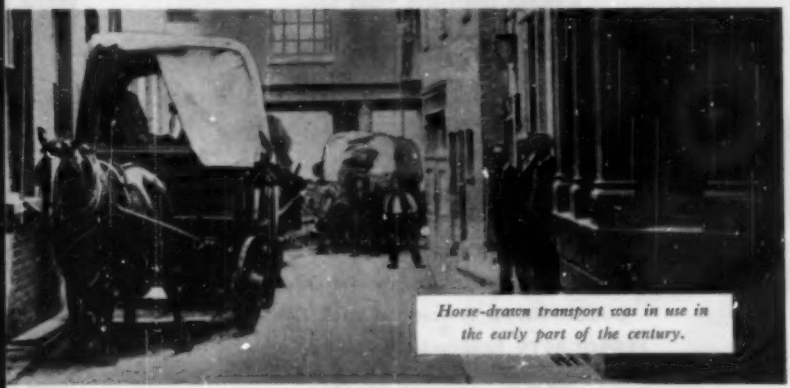
The clay grab illustrated above, in use in 1905, is shown in contrast with a modern scraper-type excavator which digs approximately 40 tons an hour.



An old testing house.



The Central Testing Laboratory of The Blue Circle Group, opened in 1952.



Horse-drawn transport was in use in the early part of the century.

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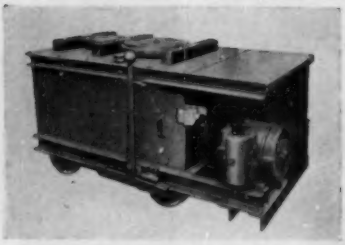
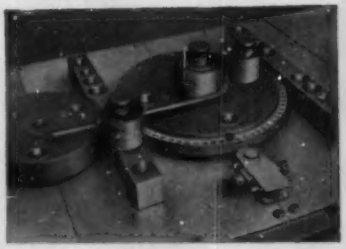


The **LACO** power-operated Bar Bender will handle round bars up to 1¼" diameter. Several bars can be bent simultaneously according to the diameter of the material.



Main Features:
Two Turntables revolve simultaneously, the fast Turntable at more than 10 r.p.m., enabling a 1" hook to be bent in 3 seconds; the slow Turntable at 2½ r.p.m. will bend a 1¼" hook in 12 seconds.

Feeding: Bars are fed into the machine from left or right. Hooks are made clockwise or counterclockwise. Flexibility of the machine ensures minimum handling of the bar during operation. **This saves time.**

Automatic Stop: Turntables can be set to stop automatically at any angle to an accuracy of ½". Identical bends are repeatedly obtained.

All gears steel and precision cut, pinions of heat-treated alloy steel. All shafts, even the slowest, fitted with grease-packed ball bearings.

Ease of control: One control only. Hand lever integral with foot pedal for operating machine in either direction.

CAN BE FITTED WITH EITHER 2½ H.P. ELECTRIC MOTOR OR ALTERNATIVELY 3½ H.P. GASOLINE ENGINE.

Maintenance negligible.

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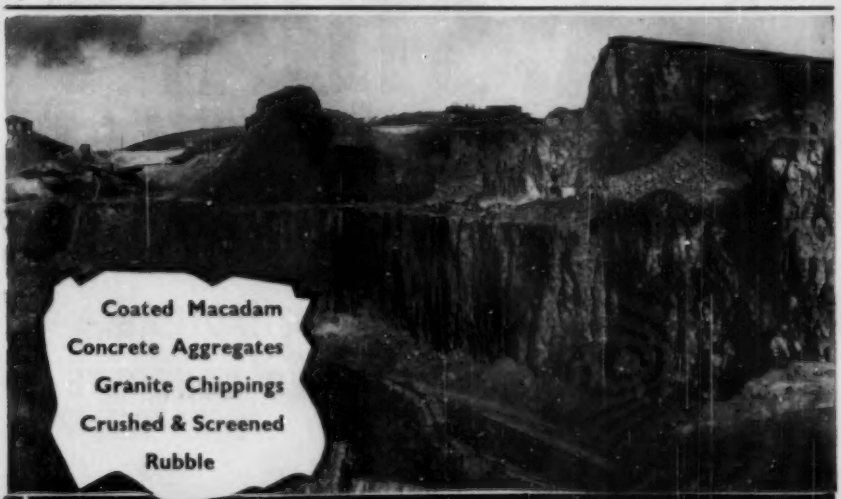

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Springfields, Nr. Dudley, Worcs.

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Water Purification Works constructed in reinforced concrete for the South Staffordshire Waterworks Company. Mr. R. A. Robertson, B.Sc., M.I.C.E., Engineer of the Company. Reinforced Concrete Designer: Mr. H. C. Ritchie, M.I.C.E.

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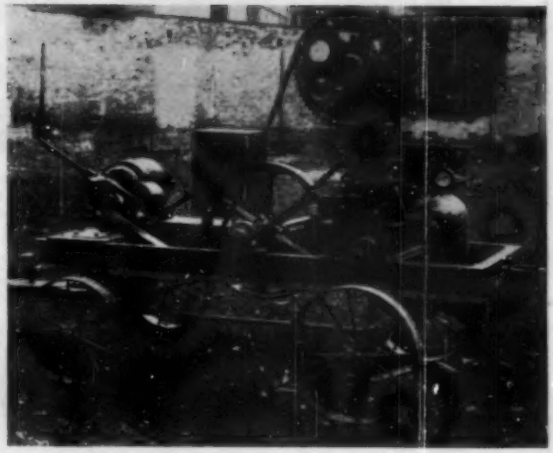

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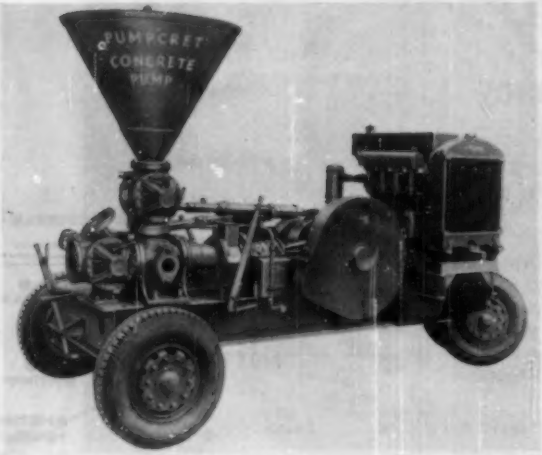

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Range:		
Horizontal, approx..	1500 ft.	1250 ft.
or Vertical, approx..	135 ft.	125 ft.
Pipeline	6" i.d.	4½" i.d.
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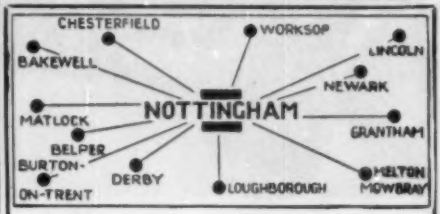

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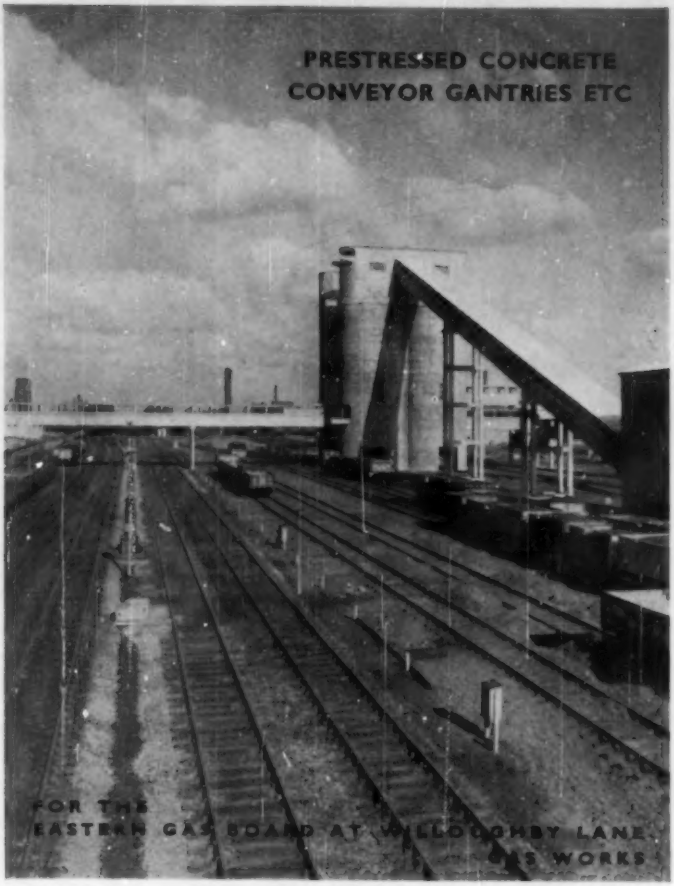

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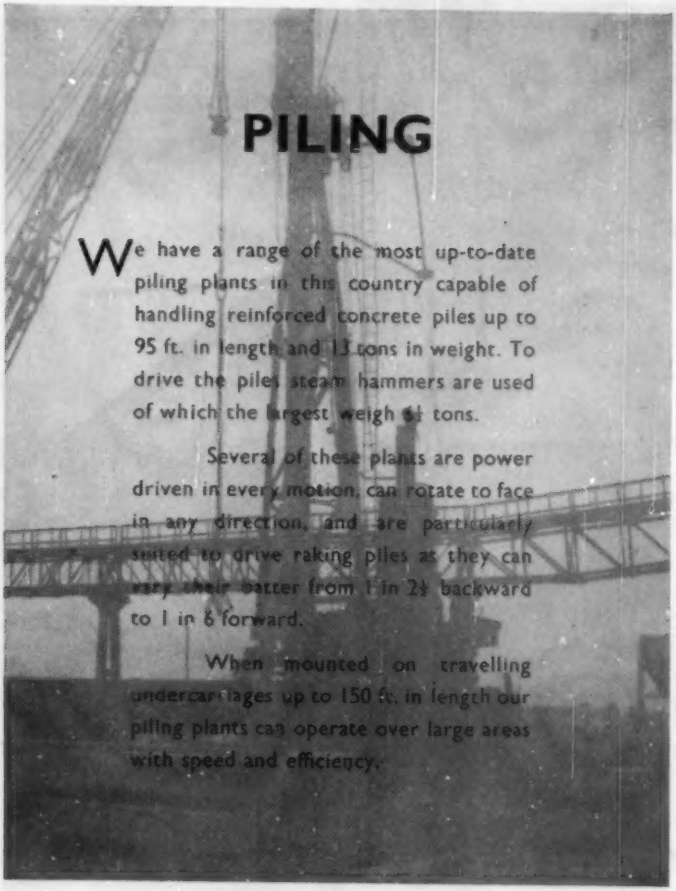
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We have a range of the most up-to-date piling plants in this country capable of handling reinforced concrete piles up to 95 ft. in length and 13 tons in weight. To drive the piles steam hammers are used of which the largest weigh 5½ tons.
Several of these plants are power driven in every motion, can rotate to face in any direction, and are particularly suited to drive raking piles as they can vary their batter from 1 in 2½ backward to 1 in 6 forward.
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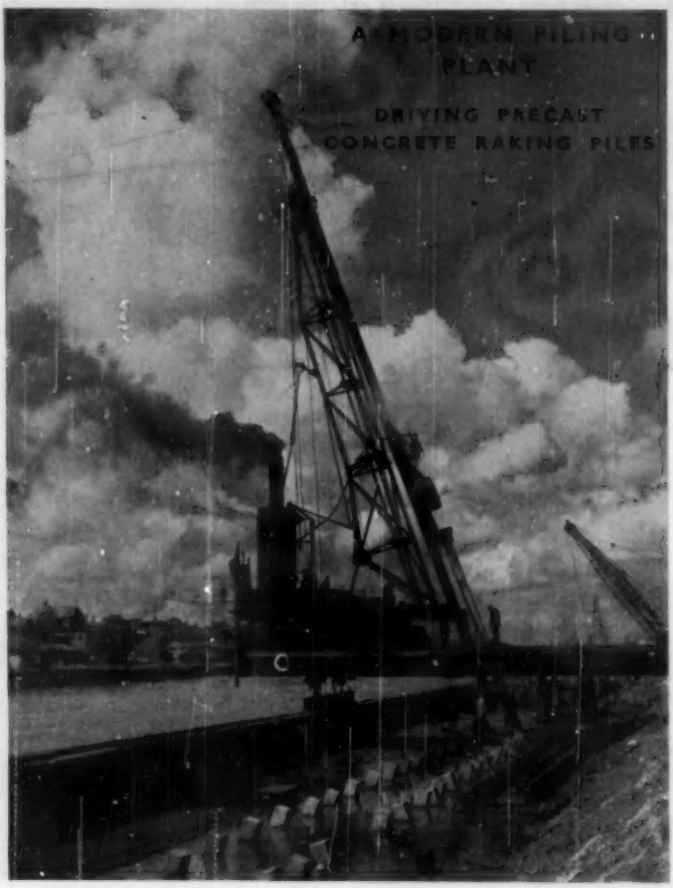

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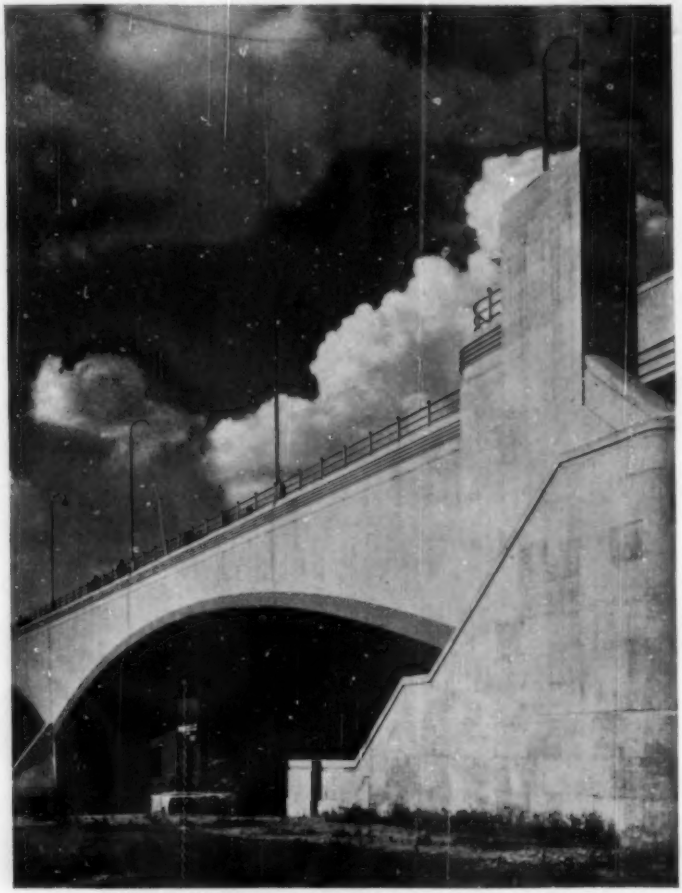

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Appointed Architect:
Sir Giles Gilbert Scott, R.A.

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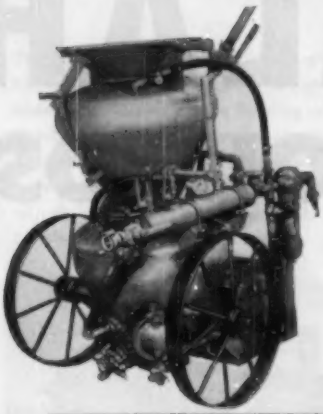

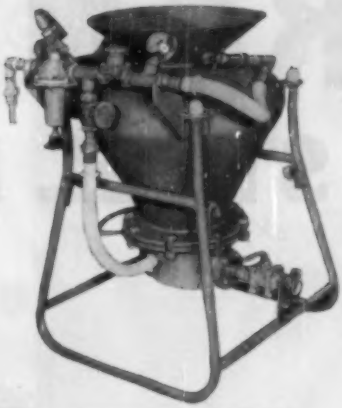

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BOULDER CONCRETOR *Build, Protect, Repair* . . . . . .

Gunite is renowned for its durability and remarkable resistance to salt water, chemicals, and fumes. The Boulder Concretor (illustrated on the left) is simple to operate and the low cost of application makes it suitable for jobs where gunite is not normally specified. It will cover 360 square feet of vertical walling 2" thick in one hour.

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The machine (illustrated on the right) is ideal equipment for placing low to medium pressure grout in tunnels, mines, etc., raising road and floor slabs, consolidating bridge piers, general foundations, rock fills, and the stabilization of railway embankments, etc.

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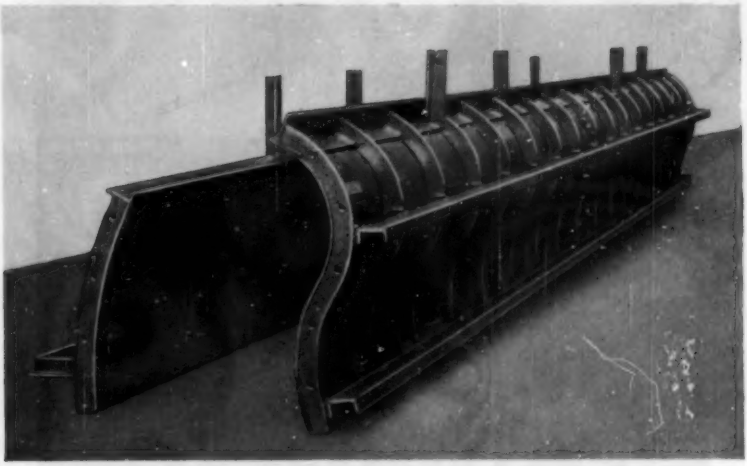

Sea Defence Mould, shown by kind permission of Brighton County Surveyor.

Solidly constructed Standard Moulds of many types from stock or specially made to your drawings. Speedy and competitive. Kerb, Garden Edging, and Coping Moulds to B.S. 340–1950.

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The illustration shows one of the piers of Kodalia Bridge (Pakistan), which was undermined during severe flooding in 1954. The COLCRETE PILES can be clearly seen exposed, and although the piles were subjected to considerable scouring action and to excessive bending moments, they remained in perfect condition.

* Note the mark of the high-flood level on the pier.

COLCRETE PILES

COLCRETE PILES throughout their length are of consistently good quality. When driven in waterlogged ground, there is no danger of water penetrating into the pile and weakening the matrix.

COLCRETE before setting exerts an outward pressure exceeding twice that of water, and the material of the pile is forced into intimate contact with the ground. Thus the pile acts as a short column and the need for steel reinforcement is reduced to a minimum.

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In 1916

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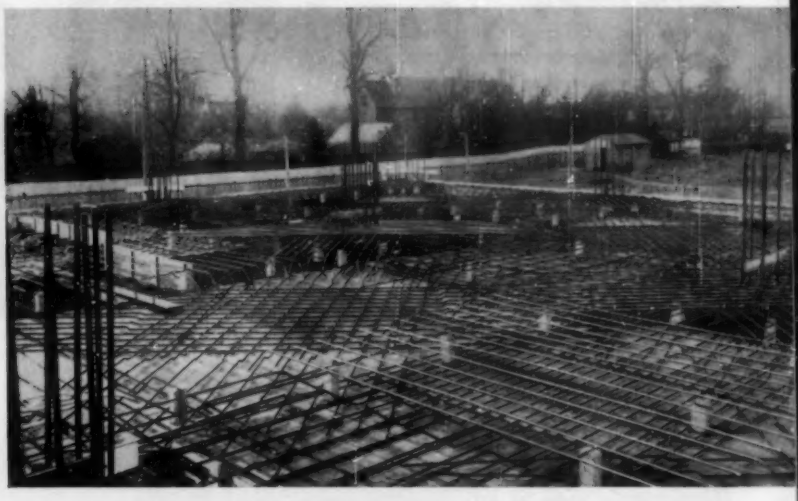

possibly the earliest flat-slab structure in this country. The columns are at 25 ft. centres and the imposed load 2½ cwt. per sq. ft.

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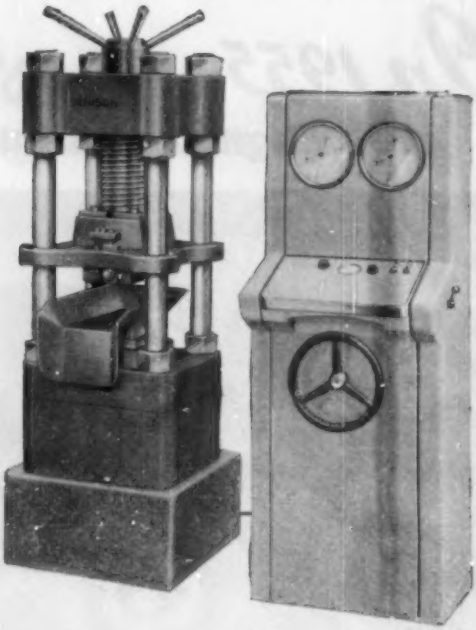

DENISON MODEL TIA/MC
COMPRESSION TESTING MACHINE
for concrete cubes, cylinders, bricks etc.

An extremely accurate machine with capacities of 100, 150, 200, 250 and 300 tons, the TIA/MC comprises a Loading Unit and a Console which can be arranged to suit individual needs.

The Loading Unit is rigid, robust, and easily accessible from all sides. An almost pulsationless oil pump ensures smooth loading. A Load-Pacer can be fitted for loading at a constant and predetermined rate.

The Console houses the load gauges, pumping unit and controls. Its remoteness from the loading unit minimises shock to the load gauges.

The design, craftsmanship, and outstanding performance of this machine are the result of 85 years of experience in testing-machine manufacture.

Full details of the TIA/MC will be gladly sent on request

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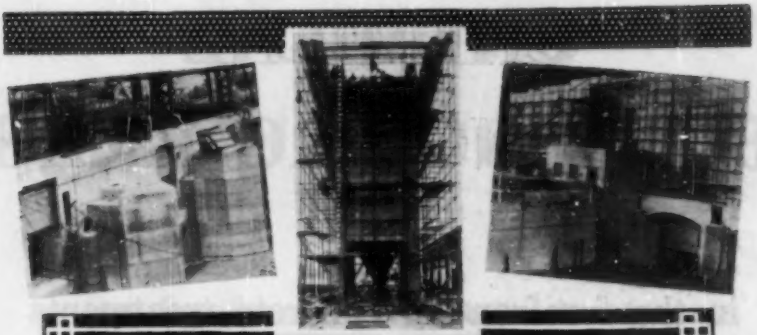

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Highly adhesive to smooth surfaces; eliminates hacking for key

CEBEX 113

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for heavy machine bedding

CONBEX

EXPANDING PLASTICISING GROUTING MATERIAL

for post-tensioned concrete work

WETEXI 'B'

COLOURLESS WATERPROOFING IMPREGNATION

for treatment of damp walls, etc.

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RANGE OF BITUMINOUS LIQUID and PLASTIC COATINGS

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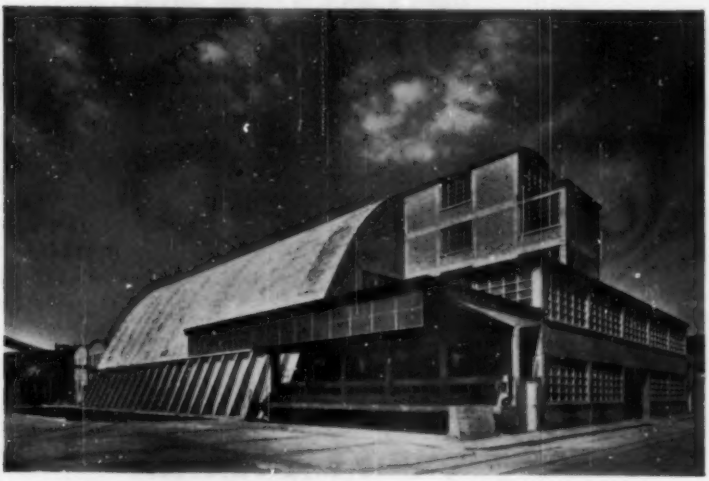
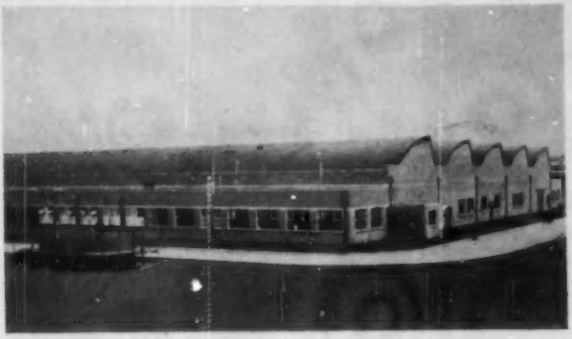


A store for 10,000 tons of Sulphate of Ammonia, recently completed for the South Eastern Gas Board at their Phœnix Wharf Chemical Works, Greenwich.

Construction is of Precast 3-Hinged Arches, the constituent Rib members being Post-tensioned Prestressed concrete weighing over 10 tons. The roof panelling is of Pre-tensioned Prestressed concrete planks, three inches thick.



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Public Works Contractors

This section of a new Sea Wall on the Kent Coast is part of extensive Sea Defence Works carried out by The Demolition & Construction Co., Ltd., during the past few years.

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Reconstruction of Westminster House, St. Mary Street, Cardiff, for Henry Budgen & Co., Ltd. Architects : P. G. Budgen & Partners. Engineers : Ecrofnier & Partners Ltd. Contractors : E. A. Bond & Co., Ltd.

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HOLLOW PRECAST CONCRETE FLOOR AND ROOF UNITS

were used throughout this office building

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Your enquiries are invited, and we shall be glad to assist you with design and technical details, estimates and drawings.

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SONS & CO. (LONDON) LTD.

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Illustrations of some of the reinforced concrete contracts carried out by us during the past 50 years are reproduced on pages cxlviii–cl.

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SPECIALISTS IN PREPAKT CONCRETE CONSTRUCTION

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Telephone: Sloane 0036

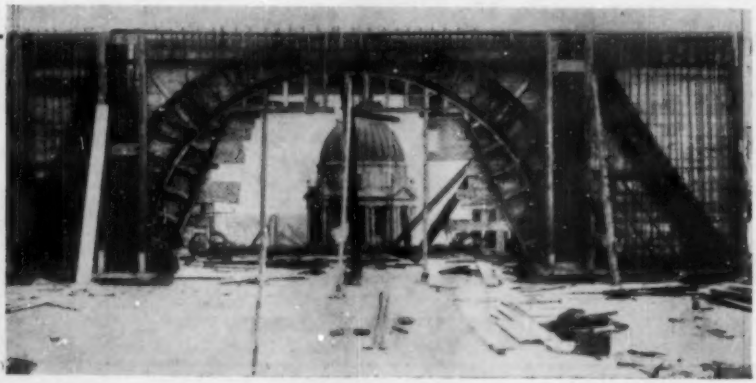
K/AD

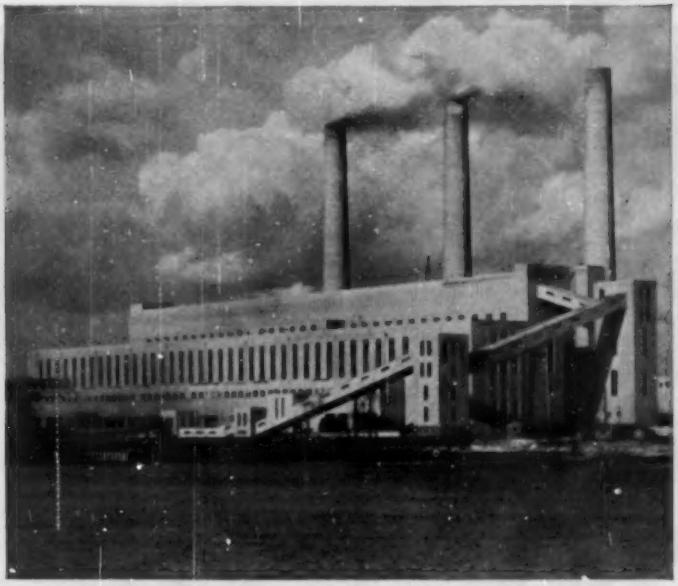
[See also pages cxlviii–cl.

See also pages cxlvii, cxlix, cl.]

NUTTALL'S CONTRACTS OF 50 YEARS AGO

include the construction of Brocklebank Wharf, the piling for which we show in course of construction in the illustration above, and the Royal Liver Building, Liverpool, of which we illustrate below the reinforcement in position for one of the arch beams.

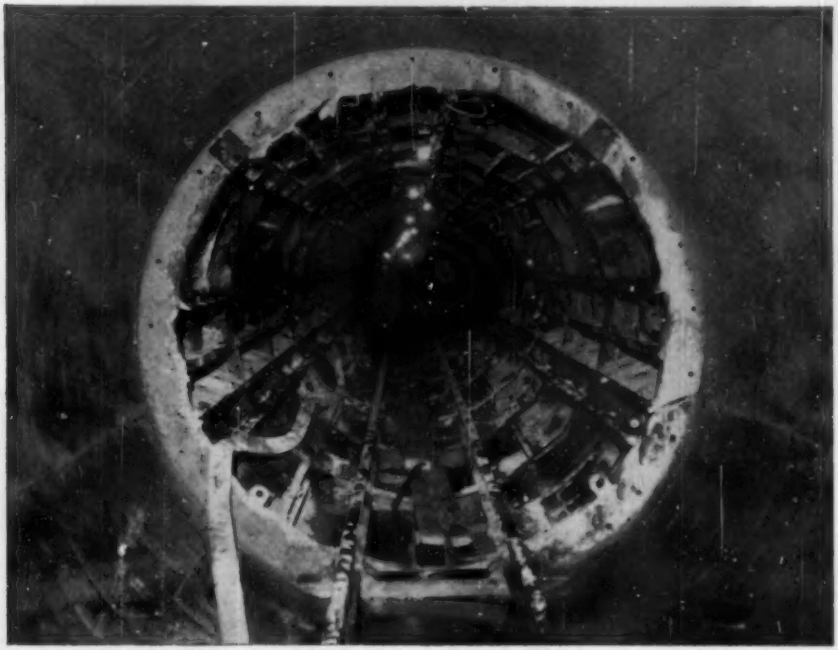




Recent contracts of ours include Cliff Quay Generating Station, Ipswich (above), for the British Electricity Authority. Consulting Engineers: Merz & McLellan and Sir Alexander Gibb & Partners; and Northern Outfall Works at Beckton (below) for the London County Council. Engineer: J. Rawlinson, C.B.E., M. Eng., M.I.C.E.

[*See also pages cxlvii, cxlviii, cl.*

See also pages cxlvii–cxlix.]



Part of the eleven-miles-long Haslingden and Walmersley Tunnel section of the Haweswater Aqueduct recently completed by us for the Manchester Corporation. Engineer: Alan Atkinson, M. Eng., M.I.C.E., M.I.W.E.

Claerwen Dam constructed by us for the City of Birmingham Water Department. Consulting Engineers: Sir William Halcrow & Partners

EDMUND NUTTALL SONS & CO. (LONDON) LTD.
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that meets all requirements for high speed, economy and simplicity of operation

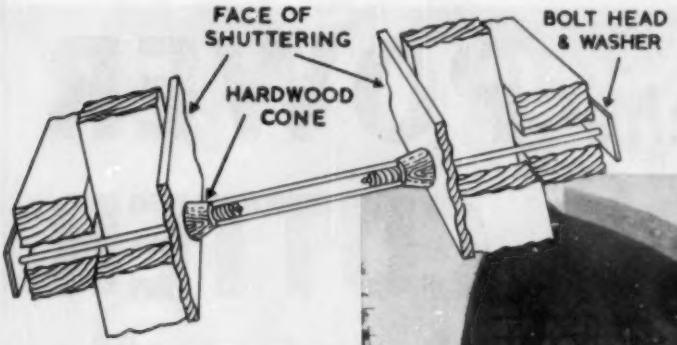
We illustrate here our BRRL. 50A Model high-speed shearing machine for cutting mild steel rods up to 2-in. diameter. This machine, of robust construction yet still portable in view of its compact arrangement, is powered by electric motor and self-tensioning Vee-belt drive. The moving blade is in continuous action and makes 28 cuts per minute; 2-in. diameter mild steel bars require one cut only. The static blade is housed in a specially-designed seating which spreads the shearing thrust over a wide area, thus reducing wear and considerably lengthening the life of the machine.

★ Full details of this Power Bar Cutter and our complete range of Bar-Bending equipment, described on pages cliv and clv, will be sent on application to :

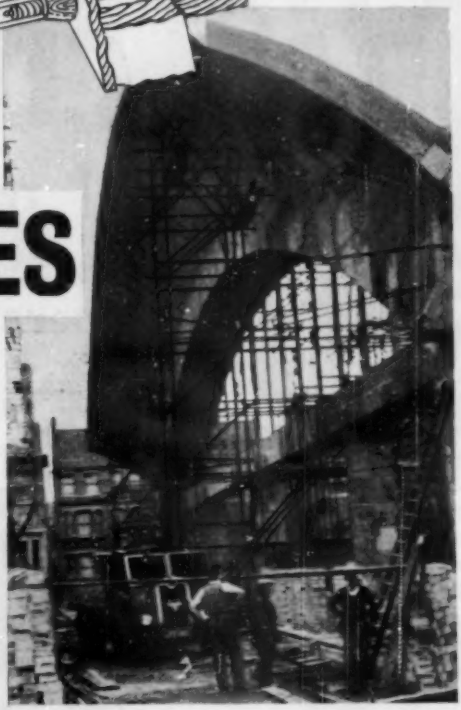
CEMENT & STEEL LTD.

SECOND AVENUE CHATHAM KENT

Telephone : Chatham 45580 *Telegrams and Cables : Cembelgi, Chatham*



RAWLTIES



Save time, timber and money on formwork by using Rawlties. With Rawlties your shuttering is fixed or dismantled in a matter of minutes; each lift after the first is self-supporting and needs no struts! Rawlties, Rawloops and Rawlhangers have been used in many of the greatest concrete constructions of our time: they will cut *your* costs, big jobs or small. Write *now* for technical broadsheet Publication No. R1401, which is full of practical information on shuttering problems.

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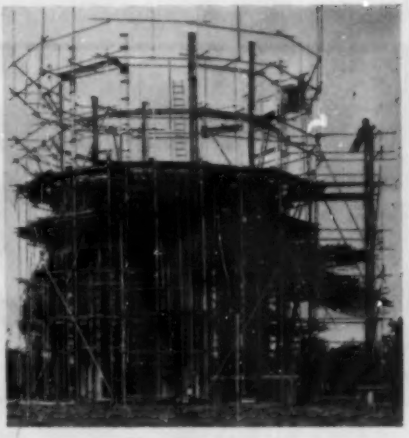
1934

Water Tower for Hitchin R.D.C. at Weston, near Letchworth.



1955

Water Tower for Thorne R.D.C. at Sykehouse, near Doncaster.

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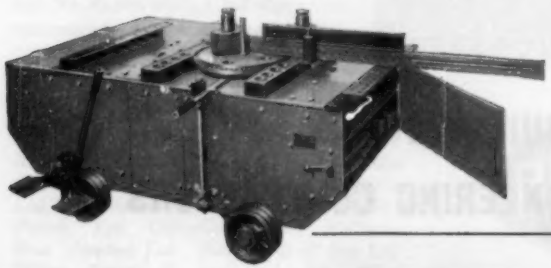
THE 1956 ARD.50 MODEL illustrated at the top of the facing page is a machine to e accuracy, simplicity and economy in all bending operations. The machine has an autc control which permits the desired bending angle to be pre-set, greatly facilitating repe bending. The ARD.50 is a twin-head machine to bend all diameter bars from ¼" to 2". illustration in the centre of the facing page shows the bending of an angle loop in one oper and the bottom illustration on the facing page shows the ARD.50 fitted with the ba cage for multiple bending of small diameter bars. This machine is supplied complete standard accessories for bends on a 4D basis and can be fitted with Electric motor, Air-c Petrol engine or Air- or Water-cooled Diesel Engine.

THE 1956 RAS.40 MODEL illustrated below is a single-disc machine which is sp designed for an extraordi high-bending production o up to 1½" diameter. A full takes three seconds' be time. This model can be su motorised or Engine driven



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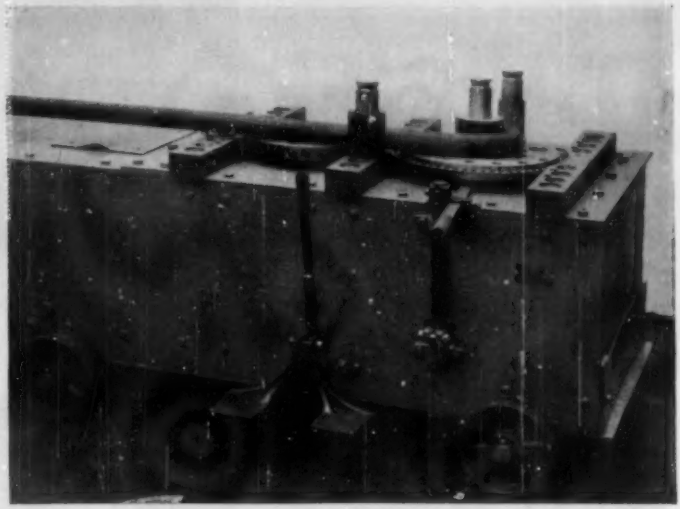
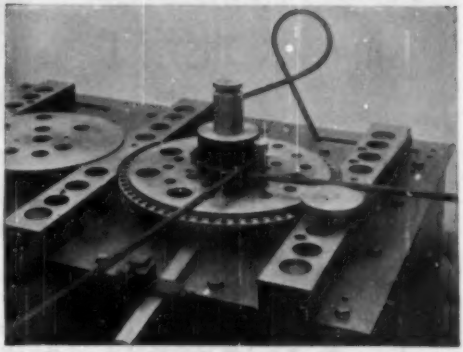
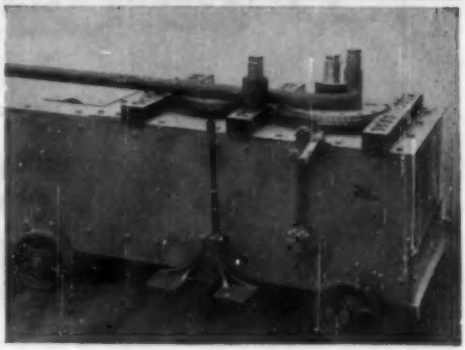


1956 ARD-50 MODELS

FOR SALE OR HIRE





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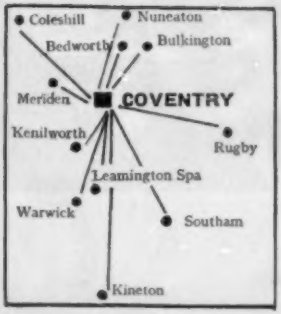

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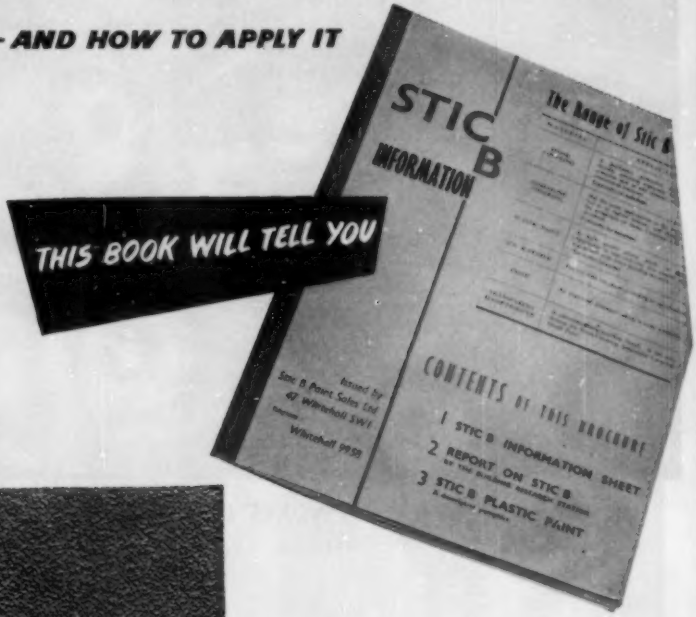
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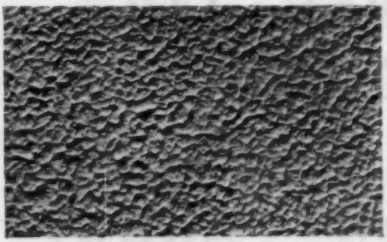

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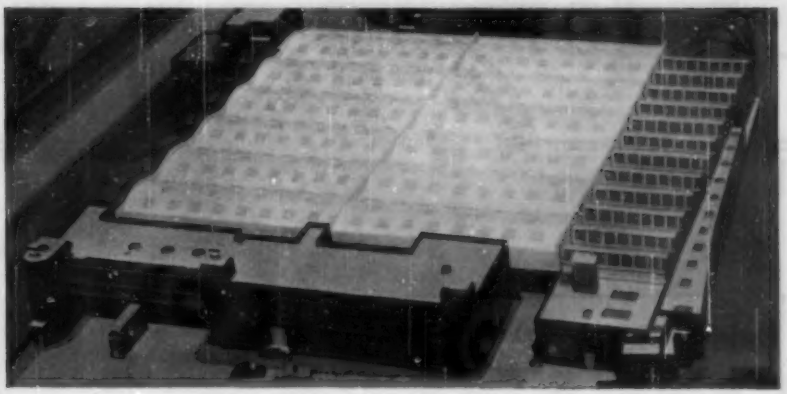

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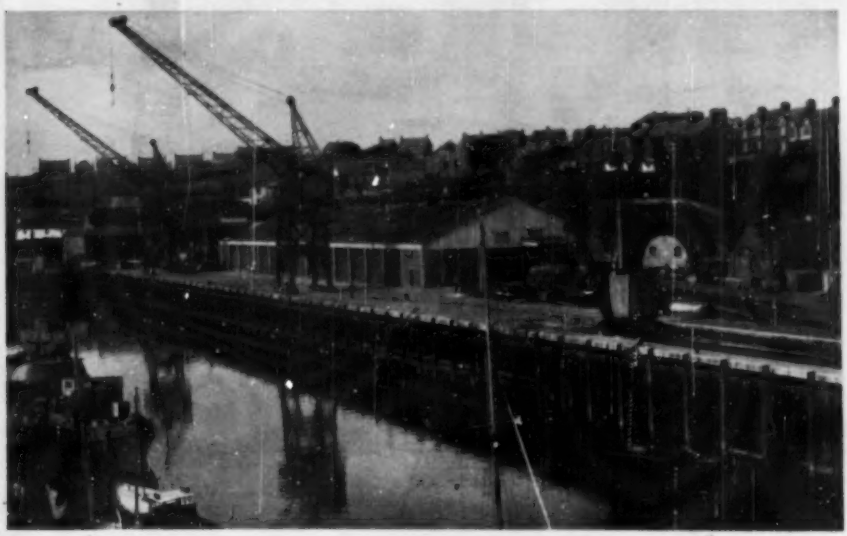

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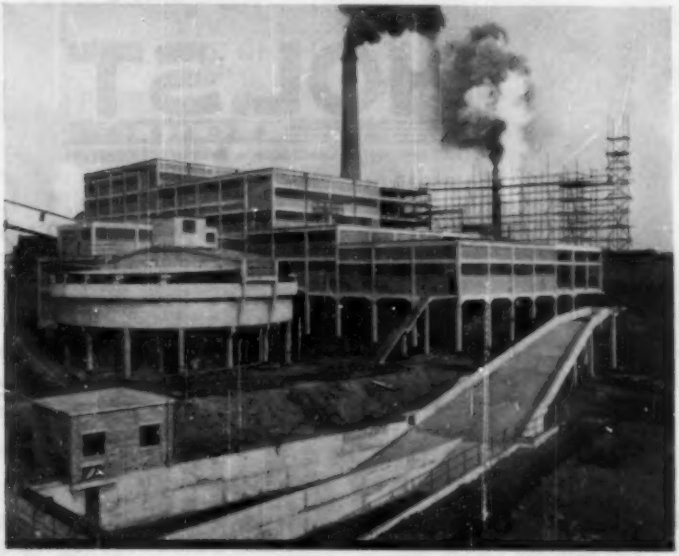
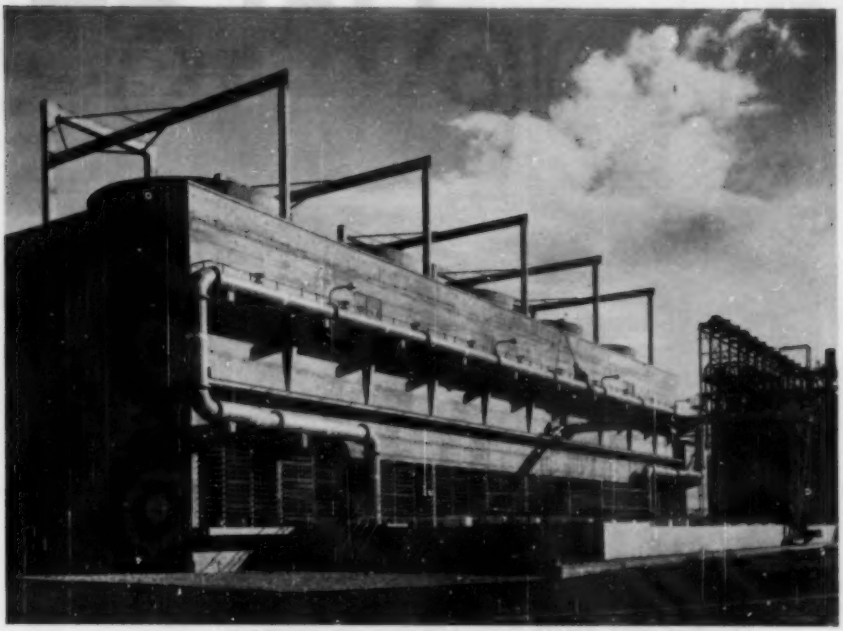


COAL-WASHERY BUILDINGS AT MOSLEY COMMON COLLIERY, MANCHESTER



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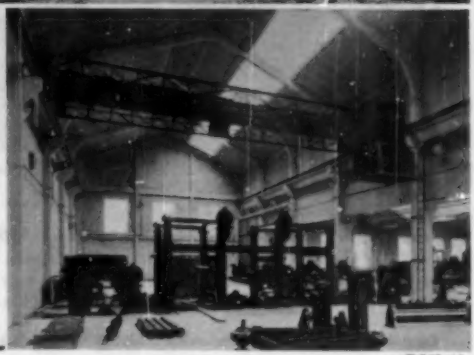
above: A precast framework for a factory for Weatherley Oilgear, Ltd., at Biggleswade.

right: A 40-ft. span crane gantry bay in a factory for Filmer Bros. at Chatham. *Architects:* Messrs. Winter & Pickering.



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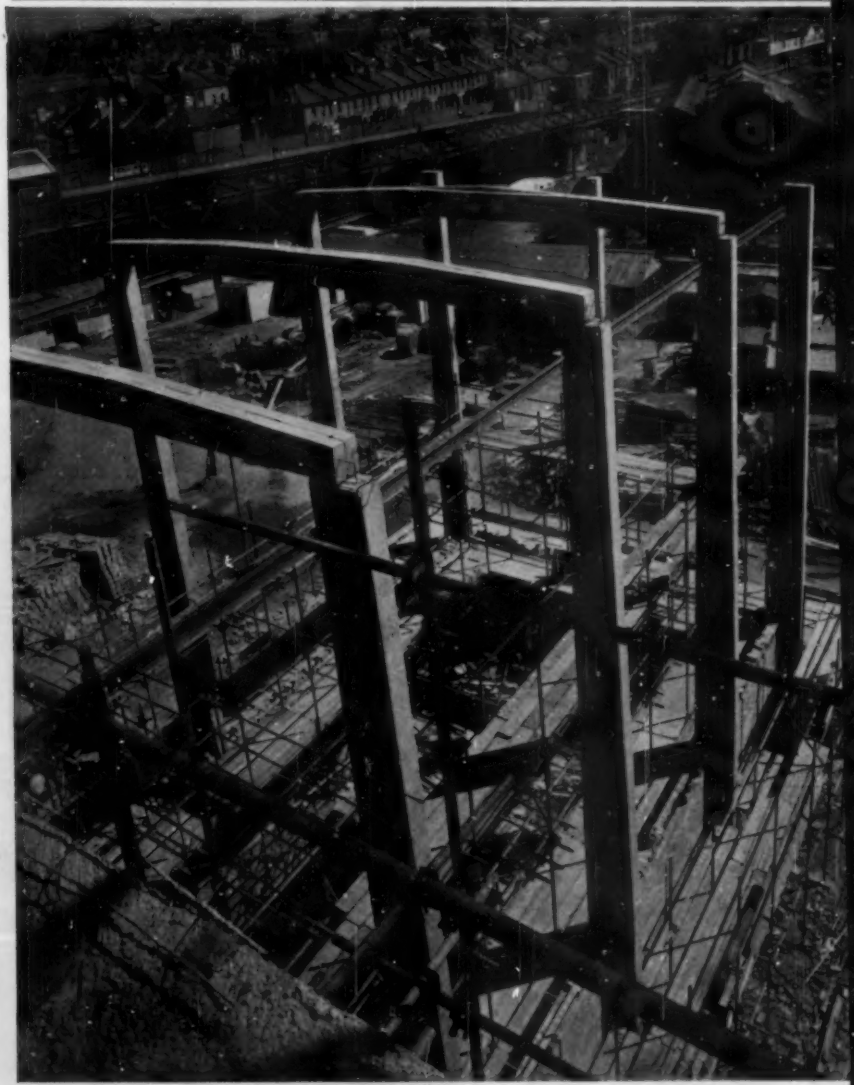

Architect: Graham Dawbarn, C.B.E., M.A., F.R.I.B.A., (Norman & Dawbarn), in association with M. T. Tudsbery, C.B.E., F.C.G.I., M.I.C.E., (The Civil Engineer to the B.B.C.).
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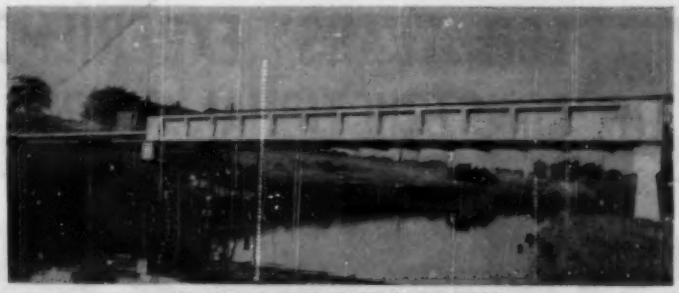

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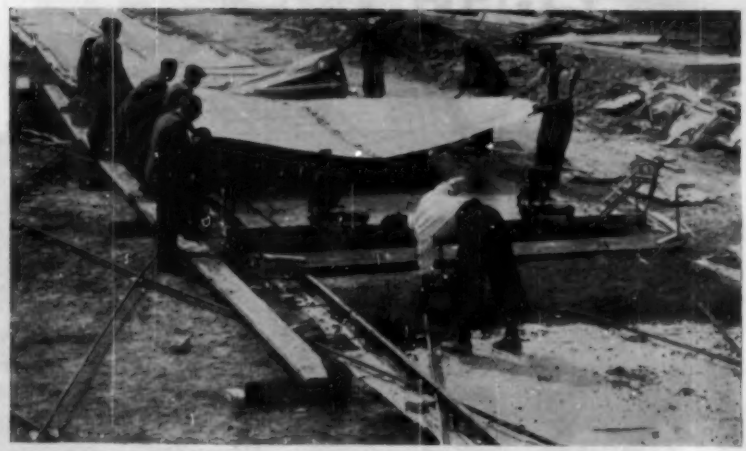

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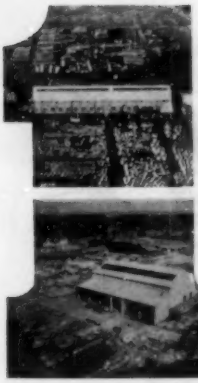

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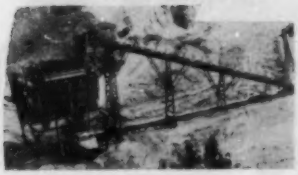

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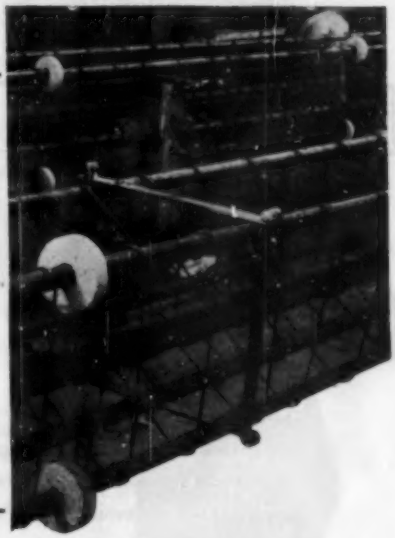

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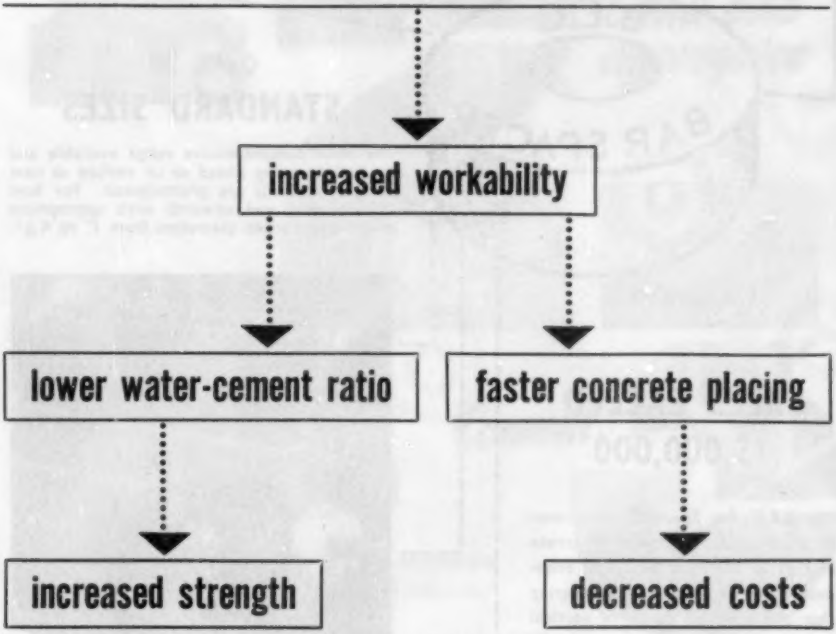

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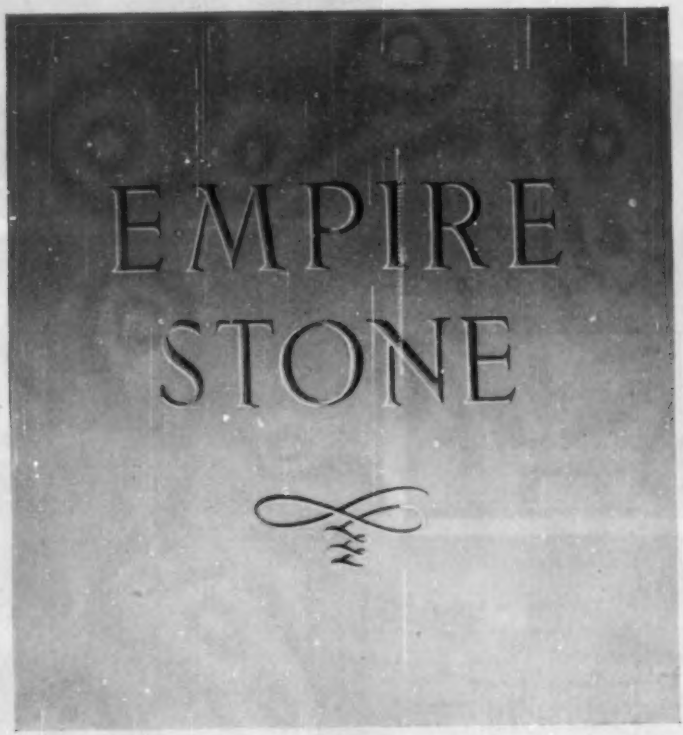

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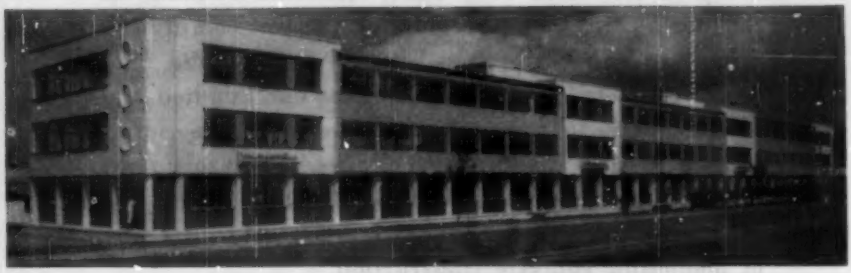

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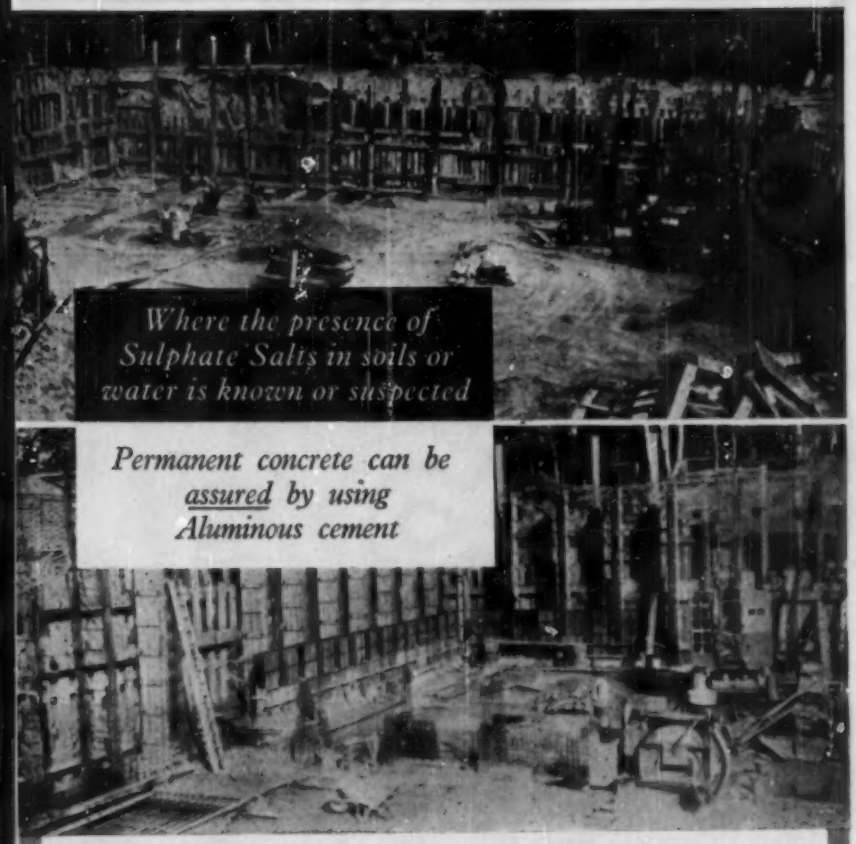

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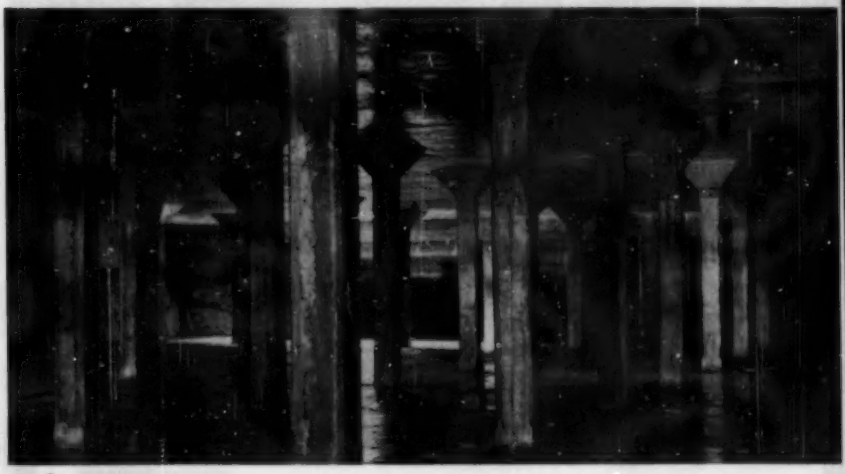

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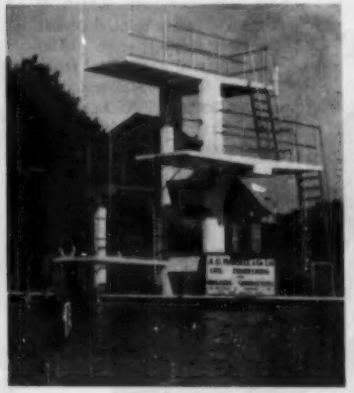

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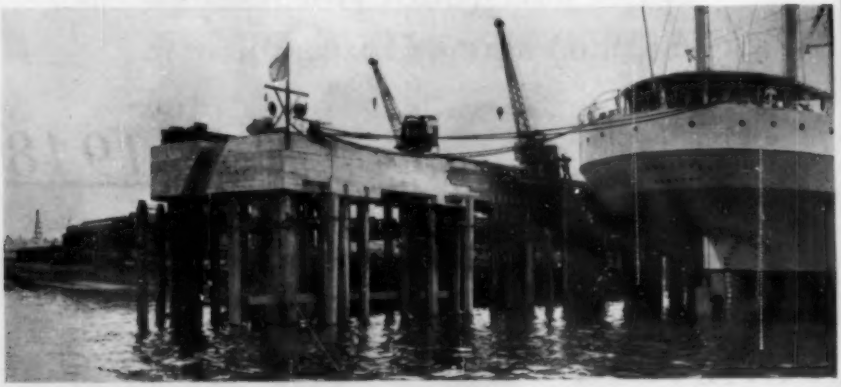

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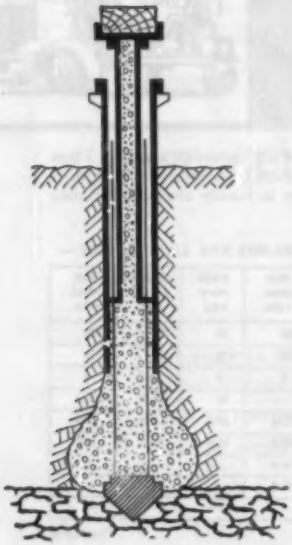

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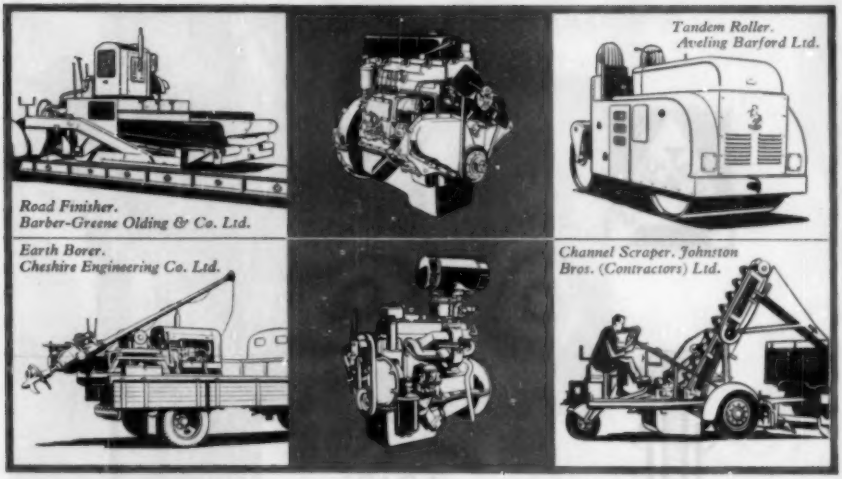

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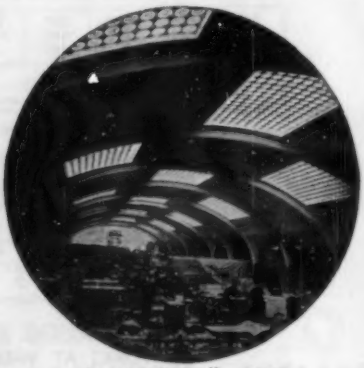

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Volume LI, No. 1. LONDON, JANUARY, 1956.

OUR FIFTIETH ANNIVERSARY.

WITH its last number this journal completed its fiftieth year of continuous publication. Half a century is not a long life among journals devoted to construction, but it covers nearly the whole of the history of reinforced concrete in Great Britain, where the first such structures were built a few years earlier.

In this fiftieth anniversary number pride of place must be given to the late Edwin O. Sachs, whose enthusiasm for the new material led to the foundation of this journal, with the aid of others who had faith in the future of concrete and who gave unstinted financial support in the risky business of starting an expensive periodical on a subject in which few were interested and against which many were prejudiced. The journal had, indeed, to popularise a new material before it could hope to have enough readers to make it a financial success and, partly due to the difficulties caused by the first world war, more than twenty years passed before the founders received a return on their investment.

Few were better qualified for the task of editing and managing the new journal than Edwin O. Sachs, who, at the age of thirty-six, gifted with dynamic energy and a pioneering spirit, showed, not for the first time, far-seeing accuracy of judgment, for the materials and methods he advocated have been proved to be sound, whilst the general format and the objects of this journal remain in substance unchanged. He believed that the confidence of readers could be preserved only so long as the editorial pages were free from pressure by advertisers and commercial considerations, and that a large circulation amongst readers who found the journal useful, and who trusted and respected it, was the best means of attracting the advertisements that would make the venture self-supporting or profitable.

This journal constituted but one of Sachs's activities. The other spheres that absorbed his energies, and in both of which he achieved an international reputation, were the design of theatres and the prevention of fires. Between 1896 and 1898 he published, in three monumental volumes, "Modern Opera Houses and Theatres", which he started to compile at the age of 24. Quickly recognised throughout the world as a standard work, it is still

EDWIN O. SACHS.
1870–1919.

THE FIRST EDITOR OF
"CONCRETE AND CONSTRUCTIONAL ENGINEERING."

regarded as fundamentally correct in its approach and recommendations, and is still a basic textbook on the subject. To have achieved such a task before the age of 28 was no mean feat, but it did not prevent him pioneering in technical matters as well. In 1898 at Drury Lane he was the first to apply electrical power to the working of the stage. He was also retained to assist at other theatres, and in 1899, when still under thirty, he was entrusted with the modernisation of the Royal Opera House, Covent Garden; there he continued as technical adviser, an appointment he was proud to hold for the rest of his life. He was one of the principal driving forces responsible for fire regulations in theatres, and in particular for the compulsory installation of safety curtains.

But above all he is remembered for his devoted work as Chairman of the British Fire Prevention Committee which, at the early age of 27, he founded in 1897. Appalled by the loss of life in disastrous fires in the 1890's, he served as an ordinary fireman in the fire brigades of Paris, Berlin, and Vienna, taking his part in combating fires in those capitals. Thus armed with practical experience, he gathered around him a group of public-spirited men, including the then Earl of Londesborough, the late Robert Mond (brother of the first Lord Melchett), Ellis Marsland the architect, and Sidney G. Gamble (Second Officer of the London Fire Brigade), who helped him to constitute the British Fire Prevention Committee, and to erect Europe's first fire-testing station within hail of Lord's Cricket Ground. Much of the work of that Committee has been taken over by the Government and developed at the Fire Research Station at Boreham Wood. Again Edwin O. Sachs laid foundations that have endured.

He became Vice-President of the International Fire Service Council, a principal organiser of international fire exhibitions, and a protagonist throughout Europe of every form of fire-fighting. Between 1900 and 1912 he received decorations from the hands of the Czar, the Kaiser, and the President of France, as well as from the rulers of Sweden, Belgium, and Luxembourg. But of all his honours he was proudest of his election as a Fellow of the Royal Society of Edinburgh.

In 1911 he was overtaken by an illness for which no cure was then known. Eminent doctors pronounced the end to be inevitable within months. But a remarkable constitution and the devoted nursing of his wife enabled him to surmount this and later crises, and gave him periods of sufficient health to follow his three absorbing interests—this journal, theatre architecture, and above all fire prevention. During the 1914–1918 war, in spite of his ill-health, he rendered public service by acting as Commissioner of the Special Fire Survey Force. Few men can have more closely followed their family motto—" Nec domitus unquam ". The active pursuit in all weathers of the duties of that appointment led to the final onset of his illness. When he died in 1919 at the age of 49 he left a widow who survived him some thirty years, and a son, The Hon. Sir Eric Sachs, now a Judge of Her Majesty's High Court, who has kindly lent us the photograph reproduced on page 2.

After the death of Edwin O. Sachs, and in the difficult conditions at the end of the first world war, the advice of Dr. Oscar Faber, C.B.E., was

sought on editorial matters, and his wise guidance was of untold value during that period. In 1922 the writer was, at the age of twenty-nine, appointed to edit the journal and to manage and develop the business, and has since striven to maintain the high ideals set by E. O. Sachs and some of the editors with whom he had worked, notably W. T. Plume, a former editor of "The Builder", who is happily still with us. Thus in the period of fifty years the journal has had two editors only. There has also been continuity in other directions, for the same printers (Messrs. Butler & Tanner, Ltd., of Frome) have printed the journal since the end of the first world war, and no editor or publisher could be more fortunate in having the assistance of such excellent printers jealous for their craft, who are also good friends and willing collaborators.

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This number, produced to mark the fiftieth anniversary of the journal, takes the form of a symposium by some of the world's leading authorities on concrete, who describe the progress of the material in their own countries, and give much valuable advice based on their experience. Some of these contributors were actively engaged in concrete work fifty years ago: to such men is due the rapid progress of concrete throughout the world, for they had the courage to accept the new material and fight for it in the face of much opposition from many of the authorities that controlled building as well as from most of the architects and building owners of the day. They were the pioneers who cleared the way, and made progress easier for those who followed them in developing the uses of concrete. The early numbers of this journal show that generally the present method of design is the same as was devised in those days and even earlier, and many of the structures then built (some of which are illustrated in this number) are still in use. In thanking these pioneers for their efforts as young men in establishing and making acceptable reinforced concrete as a structural material throughout the world, we must also thank them for the friendly way in which they accepted our suggestion that they might contribute to this number; most of them said they were honoured by the invitation—we would rather say that we are honoured in having the privilege of publishing such valuable contributions from such eminent authorities. Apart from the descriptions of structures old and new, these authorities give much wise advice and many valuable suggestions that should be studied by all interested in concrete, whether practising engineers or juniors, and we are grateful to them for their collaboration. Articles by French engineers are given precedence because reinforced concrete and prestressed concrete originated in France; the other articles are inserted in the order in which they were received.

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On this occasion a few words may be said on the policy of Concrete Publications Limited. So far as we know, this journal is unique in that its price has remained unchanged for nearly forty years. It is the policy of the Company to provide literature on concrete as cheaply as possible, and the fact that the price has remained unchanged is due to the constantly increasing sales and advertisement revenues. The low prices of the books

published by this Company have also been often commented upon, and here again the reason is large and increasing sales.

The unit cost of producing books and periodicals depends very much on the number printed at one time, and the great demand for this Company's publications results in such large printing numbers, and consequently low cost per copy, that the ever-increasing cost of production has been met by increased sales at pre-war or very slightly higher prices. So far more than half a million "Concrete Series" books have been sold, and some of them, with sales so far of nearly forty thousand copies, would be classed as "best sellers" by publishers of novels or any other class of book. The success of these books is in no small measure due to the late W. S. Gray, a sound engineer with an encyclopædic knowledge of concrete, who from 1928 until his death in 1945 was a member of the staff of the Company and found time to write some of these books himself.

In the early 1920's some of the most popular textbooks in use in this country were of American origin. There were, of course, some excellent books by British authors, but more were needed if British students and British engineers were to have a sufficiently wide selection of British books. It was therefore decided to start the "Concrete Series" books, and the guiding principle was to make available good books at low prices in the confident expectation that such a policy could not fail to be a financial success. The late Reginald Hallward, who had the distinction of being the only living artist whose decoration adorned Westminster Abbey, drew the border and colophon used on the title pages; he was asked to take as his motif the fact that the books were British, and produced a design of English oak leaves and acorns and English heraldic lions. When it was suggested that our friends to the north and west might demur at the omission of the thistle, the leek, and the shamrock, he said that this would spoil the design—and who would care to argue about art with such an eminent artist? It is a source of great gratification that some of these books, of which nearly fifty have been published, are now used as textbooks in American universities. In the 1920's also the "Concrete Year Book" was first published, and two new monthly journals were started. Of the total sales, about two-thirds of the "Concrete Series" books are exported, and about half the subscribers to this journal are abroad; the ratio of exports of "Concrete Series" books is about double the export ratio of all British publishers. So the work of Edwin O. Sachs not only gave the concrete industry the technical information it lacked in the early years of the century, but has made possible the earning of foreign currency when it is so much needed.

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The development in the uses of concrete during the past fifty years is perhaps best indicated by the increase in the production of Portland cement. No figures are available before 1925, when the production in Britain was 3,750,000 tons, since when it has increased 3½ times to 12,750,000 tons in 1955. This is, of course, insignificant compared with developments in some other industries such as aircraft, rayon, and plastics, that have started within the past fifty years, but development will naturally be quicker with a new product than with building, whose history is longer than the recorded history of man.

The rate of increase in the use of concrete in Great Britain in the past fifty years has probably been as great as in any other country but, as has been previously mentioned in this journal, the contribution made by this country to the technical development of the material and its uses has been lamentably insignificant. It seems that every advance during this period has come from abroad, as did reinforced concrete itself. The list of developments in design, construction, materials, and plant is long. It includes prestressed concrete ; new methods of design, such as moment distribution and " ultimate load " ; " shell " roofs and domes and the use of large precast structural members ; new types of concrete such as " no-fines ", celiular, aerated, foamed, and air-entrained ; rapid-hardening, high-alumina, blast-furnace, sulphate-resisting, and " low-heat " cements ; foamed-slag and expanded clay aggregates ; the addition of pulverised-fuel ash ; cold-worked high-tensile twisted bars, indented bars, and expanded steel reinforcement ; cast-in-situ piles, chemical consolidation of soils, and " soil mechanics " ; concrete roofing tiles, wood-wool slabs, pressure pipes and the centrifugal process of pipe making ; new types of products-making machinery ; vibrators, weigh-batching machines, tower cranes, bull-dozers and other earth-removing machines ; ready-mixed concrete ; road-making machines ; adjustable shores and props, systems of steel shuttering and sliding forms ; delivery of loose cement, the pneumatic conveyance of cement and the air-slide conveyor—all these, and other familiar materials, processes, and machines were in use abroad before they were introduced into this country, which used to lead the world in inventiveness. In view of the vast sums spent on research on concrete at the universities, Government research departments, and other laboratories, it is indeed disappointing that so few contributions to the improvement of concrete design, manufacture, and construction have originated in Great Britain. Our organised research establishments appear to prefer the simpler tasks of testing products invented by others, reporting on or copying work done abroad, acting as agents in introducing foreign ideas, and issuing publications on subjects already dealt with in books and periodicals. None of these activities can be properly described as research. It is to our credit that Aspdin invented Portland cement a hundred and thirty years ago, and it is hoped that in the next half century Great Britain will nake more original contributions to the theory and practice of concrete.

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The illustrations in this number of modern work abroad give an idea of the new forms that have been devised to meet modern needs. Similar structures have of course been built and are being built in Great Britain, but as these have mostly been recently illustrated in this journal they are not given again in this number.

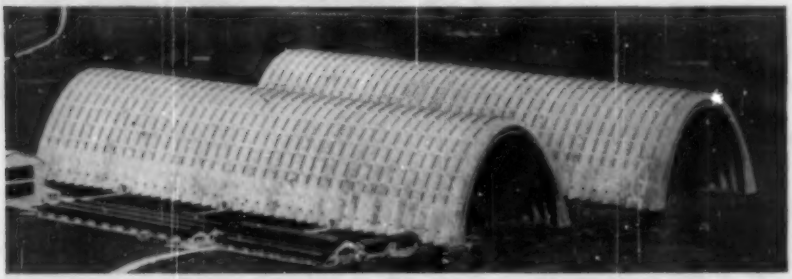
Bishop Berkeley said that our inability to foresee the future is among the greatest blessings of mankind. No one can tell what the next fifty years will bring forth, but if the development in the uses of concrete progresses at the same rate as it has done in the past fifty years future generations should have every reason to be satisfied.

FRANCE

By E. FREYSSINET

In asking me to write on engineering and architecture, the Editor of "Concrete and Constructional Engineering" does me an unexpected honour and one for which I am singularly ill equipped. I consider that an engineering structure becomes architecture only in so far as it constitutes a work of art, expressing ideas or causing emotion.

Now I am a complete stranger to all that concerns art. My heredity, my schooling, and the circumstances of my life's work have all contributed to turn me away from an appreciation of art. I come of peasant stock, from a region where a hard life leaves no place for the arts. My technical education made of me a physicist and an engineer passionately fond of his profession and ignorant of practically everything else—particularly of architecture. I have devoted myself solely to research into the properties of materials and the forms which can be given to them and to the improvement of their use and means of employment. It is true that in this field I have arrived at results which have

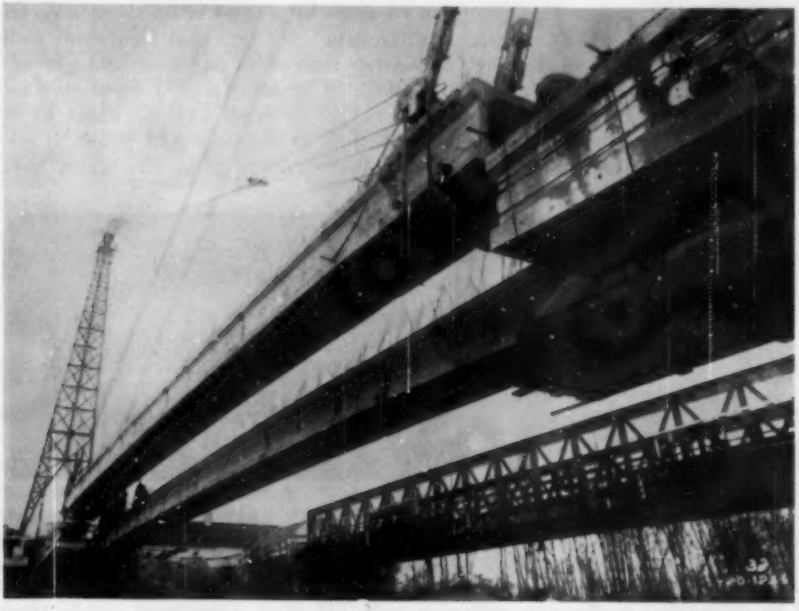


Hangars at Orly.

enabled me to lower the cost of certain forms of structure and I have been led, particularly between 1915 and 1928, to apply my ideas on a large scale; but I have aimed at exclusively utilitarian ends. If, then, I practised architecture, it was as M. Jourdain spoke in prose—without either knowing it or wishing it.

Nevertheless, it so happens that many artists have interested themselves in some of my structures, not from the exclusively technical point of view from which I designed them, but from their own; they would have it that these were works of art. It was, I think, Marcel Magne who first attracted attention to one of my works, notably when he published some photographs of the casting shed of the Caen steelworks. This shed was of a somewhat unexpected form which resulted from the best accommodation that I could find for a process requiring complex and powerful machinery. By the light of cascades of molten steel or showers of sparks from the Bessemer furnaces, this factory takes on indeed a strange beauty, recalling the moving compositions of Piranesi. Nevertheless, in building this shed in the middle of the 1914–18 war, I had one purpose only: to make steel as soon as possible to counter one of the dangers of the menacing submarine war.

It was in the hangars at Orly, now alas ! no more, that the contrast between the absence of artistic intention and the power of the effect obtained was the most striking. These buildings were the subject of a design competition between contractors. My own firm put in a price so considerably lower than all the others that we feared an error in our estimates, particularly as in the press of other work we had spent little time on the project. As a result I did my very best, more so perhaps than in any of my other structures, to reduce construction costs to the strict minimum. After much trial and error, I arrived at a com-



Esbly Bridge : Placing the Central Span.

One of five prestressed bridges, designed by M. Freyssinet, over the river Marne. Span 242 ft. 9 in. Width 26 ft. The hinges at the ends include jacks for regulating the thrust.

bination of novel structural forms capable of being built by mechanical means with little labour. and assuring ample structural solidity with a very small consumption of material. I sought no farther, and not for a moment did I give a thought to possible artistic effects. Yet the artistic effects were striking. If one entered when the main doors were closed, by one of the side doors, one received a most powerful impression. I have observed it in numerous visitors, of all levels of education and of many different nationalities. Even those with a hostile bias did not escape. This impression was not due solely to the unusual dimensions of the building ; it was above all a sense of equilibrium, of harmony and order, a spontaneous certitude that each detail was exactly what it should

Bridge over the River Marne at Ussey.

Six I-shaped prestressed arched beams on hinged supports. Span 242 ft.; depth, including road surface, 3 ft. 4 in. at crown and 8 ft. 2 in. at supports.

be, whence came a satisfaction of the emotions identical to that which we feel before a successful work of art.

How can such purely intellectual emotion result from the application of mechanical means to exclusively utilitarian ends? We can conceive of an ideal technique, a material and utilitarian perfection, which might be defined as follows.

Suppose we knew exactly all the conditions of employment a certain structure has to satisfy, as well as the strains, the causes of dislocation or ruin, that it might be required to resist. An intelligence gifted with a limitless power of invention, that knew all the properties of materials and of structural forms, and had at its disposal infallible technical means for determining at every point in the material all the effects of any change in physical conditions, would be capable of finding all the satisfactory solutions to such a problem. Among them, it would be capable of choosing that which, while harmoniously satisfying all the conditions, required a minimum of human effort for its construction. This solution would be necessary, and unique. Should it be found, we would be as

Battant Bridge at Besagon.

Span 205 ft. Ten prestressed two-pinned ribs joined transversely by prestressed slabs. Ribs 4 ft. deep at the crown.

responsive to it as to any other superhuman perfection. Just as when faced by the infinity of the sea or the sky, or a splendid landscape, or a human form of dazzling beauty, we would be lost in admiration before the manifestation of an all-powerful creator.

In the reality of our work, we have to solve problems that are imperfectly defined. On the forces that act on our structures, and on the properties of structural forms and materials, we have information that is inexact and incomplete. Far from being able to create forms of limitless number, we borrow painfully from the external world models which we adapt to our needs by slow successive transformations. Our complicated analytical means, slow and wearisome to handle, lack power and penetration and provide only rare and inexact information, quite insufficient for defining the shapes of our structures. They

Road Bridge, Bourg d'Oisans.

Span 120 ft. Width 26 ft. Girders of T-section freely supported at one end and on a concrete rocker at the other end.

expose us to frequent errors. We are thus extraordinarily remote from the conditions of an ideal technique. We can nevertheless attempt to get nearer by energetic and obstinate effort.

The engineer who shall impose this task on himself will seek to draw from the technical data of his problem all the defining conditions possible. He will compare them with structural forms which he will endeavour to create in as large numbers as possible, and modify them in every way the better to adapt them to these conditions. For each detail he will seek a solution that fits perfectly into the whole ; it will not be sufficient that this detail be good, he will require that it be the best which can be found. He will examine all his hypotheses, all the causes of force or of strain, and will ensure that the material can resist them. With absolute sincerity, he will submit the arrangements he has imagined to an incessant and lively criticism, rejecting even those that have cost him most labour as soon as he discovers in them the least defect. Accepting no

Fontaine Bridge, Grenoble.

Spans 148 ft., 180 ft., and 148 ft. Freely-supported prestressed beams.

compromise, he will tirelessly continue his search, making of it the very substance of his life. Like all men who pursue an ideal, he will need moral qualities even more than imagination, intelligence, or knowledge: probity, sincerity towards himself and others, tenacity, courage, faith in himself and in his work, passion for and pride in his task. This last will be accomplished on the day he finds from within himself the structural forms which he could not find by the application to technical data of the analytical means at his disposal. These forms will spring from his unconscious mind, dictated by an instinct that summarises all the experience that heredity has accumulated in us since the first living being of which we are the issue; they will have the inevitability that characterises all the creations of instinct, and will be its final satisfaction.

Thrown out by the force of his creative passion, these forms will be its expression. His faith and the sincerity of his effort will be written in them, all the more forcibly as his effort was the greater and the difficulties to be surmounted the bigger, in that language of the soul so mysterious to the reason but so clear to our sensibility that a few notes, a line, a harmony of colours, suffice to express our strongest as well as our most delicate emotions.

Esquerchin Bridge at Douai.

Two-hinged arch of 170-ft. span.

Road Bridge at Luzancy.

Span 180 ft. Width 26 ft. Three main girders of cellular cross section, each comprising twenty-two hollow blocks 8 ft. long, prestressed on river bank.

Our unconscious being is that within us which is most fixed and most permanent ; in everything emanating from it there is something constant and invariable that is found in all that comes from the same creator. This it is that constitutes his style, the expression of his personality. Style and the power to move the minds of others are the reflections of the creative emotion, in whatever way it expresses itself. Whatever be the inherent value and the particular nature of the ideal pursued, whether the result be a work of art will depend only on the human and moral factors placed at the service of this ideal.

An engineer without passion and without courage will seek shelters for his responsibility in precedent, habit, standard answers, giving him motives for his decision that are as foreign to his own sensibility as to the nature of his problem. He will leave a large part to chance. A structure so conceived will have no power to excite emotion. It will be boring and dull. It will shock, and be aggressively ugly, if it transgresses against traditional harmony or if its author seeks to mask his poverty by artifices that will but add the expression of his lack of sincerity and his vanity to that of his insignificance.

A Chinese painter of the Sung dynasty, celebrated for the subtle art with which he expressed the poetry of the morning mist, was asked one day by a disciple what secret made his works as moving as nature itself. " I apply myself to the task," was the reply, " with a pure heart and with all the forces of my soul." This word of a great artist shall be my conclusion. In all domains of human activity, for a man to create things capable of moving other men, it is sufficient, however modest the task, for him to fix in his mind an ideal of perfection and to strive to attain it with a heart freed from all other cares and with all the forces of his soul.

[The accompanying illustrations showing some of M. Freyssinet's work have been inserted by the Editor.]

FRANCE

By HENRY LOSSIER

ALTHOUGH reinforced concrete was first used nearly a century ago, it is in the last fifty years that the greatest progress has been made. Nevertheless, our predecessors left behind them the bases of the greater part of the views now held. More than fifteen years before the beginning of the twentieth century the German engineer Doehring patented the principle of prestressed concrete; Hennebique had given to concrete an irresistible impulse; and Considère had conceived hooped concrete, a remarkable invention in that the reinforcement resists tensile stresses which the concrete is incapable of resisting and alsc appreciably increases its compressive strength. Fifty years ago, then, far from there being no basis for the application of reinforced concrete, considerable progress had been made by our predecessors, to whom great credit is due. Let us examine successively the development of reinforced concrete and prestressed concrete.

Reinforced Concrete.

Reinforced concrete has developed in four stages, each of which exhibits a different trend varying with the views and methods of the engineers concerned. The first stage is that of the originators, the second that of the theorists, the third that of the experimenters and builders, and the fourth stage is that of the innovators. It is particularly interesting to note that although the second stage was a little remote from reality the fourth stage is marked by a tendency to return towards the first but in a state nearer perfection.

FIRST STAGE.—This was the stage of empiricism and intuition. The effects of shrinkage of concrete were hardly appreciated, and of creep completely ignored. It is notable that Hennebique, using a method of calculation in which the two resultant forces due to bending were unequal, unlike the method generally adopted for other materials, carried out some important works in the form of statically-indeterminate structures. Typical of these is the Risorgimento bridge * in Rome, comprising an arch of 100 m. (330 ft.) span but with a very small rise. Apart from some cracks, which generally were of little consequence, the bold conceptions

* This bridge is illustrated in Mr. Whitney's article on page 37 of this number.

Fig. 1.—Albert Louppe Bridge over the River Elorn.

Arches of 610 ft. span. Double decks for a road and a railway. Built by Entreprise Limousin.

of Hennebique, both in France and in other countries, because of the good engineering sense of their designer, were never affected unfavourably by any cause directly attributable to the principles underlying their design.

SECOND STAGE.—This was the stage of the intervention of the theorists in reinforced concrete. It was marked by great and substantial progress by inquiring minds, such as Considère, Mesnager, and others ; it was equally a stage of incomprehension and occasionally of lack of progress by engineers who confused arbitrary theories with a reality they did not understand. Study of shrinkage was commenced, but there was little success in explaining it. In contrast, the effects of plastic deformations and the favourable effects of adaptation, since brought to notice by M. Caquot, were ignored. Most of the tests made in laboratories to determine the properties of concrete were of very short duration and did not reveal the often important effect of time. It was realised that the strength of concrete, its modulus of elasticity, and its shrinkage had their greatest rate of increase during the first year, and then quickly became stabilised both for the effects of loads applied for a short time as well as of loads applied for a long time. These conditions led to the assumption of a constant value for the modular ratio as well as of " plane sections remaining plane ". Engineers had to submit to regulations, as arbitrary as authoritarian, that could not always be justified by experience. These regulations were made by men trained in steel construction, who did not seem to appreciate that reinforced concrete was a new material with its own characteristic qualities. The condemnation of the principle of partially-continuous beams and of hingeless arches of small rise, and the excessive reinforcement of fixed arches, are some of many examples of this false approach.

THIRD STAGE.—This was principally characterised by a better knowledge of the phenomena of shrinkage on setting and the creep (or slow deformation) of concrete compressed for a period. In 1924 the writer noted that the ties of arched roofs increased in length over a period of time. Likewise the research of Freyssinet (1926), Faber (1927), Davis and Glanville (1928–29) and others gave a more complete knowledge of creep. Ingenious and attractive theories were sought to explain the phenomena of creep and shrinkage, but with little success although the theories advanced were of practical use to engineers. However, reinforced concrete appeared at the end of the third stage not merely as an inert material but, on the contrary, as a living material with its principal characteristics varying notably as a function of temperature, of the number of repetitions of

Fig. 2.—Bridge over River Oise at Conflans.

Span 330 ft. Rise-span ratio 1/10. Width 33 ft. The arch is of rectangular cross section and is hollow except at the springings. Built by Entreprise Boussiron.

Fig. 3.—Jacques Boulloche Bridge, Bezons.

Length 670 ft. Arch spans 180 ft., 310 ft., and 180 ft. Width 80 ft. Engineers, Bureau Pelnard-Considère under the direction of M. Caquot. Built by Entreprise Van de Walle.

application of a load, and of the intensity and duration of a load. It seemed that concrete was able in time to adapt itself to new conditions in a similar way to some living organisms. In other words reinforced concrete commerced to be revealed with its own personality, very different from most other materials of construction, and this further widened the gap between the conceptions of the originators of reinforced concrete and the lifeless conceptions of theorists whose minds were fettered by the classical theories of metallic construction.

The term "classical theories" is used because metallic structures benefit also, although in a more restricted manner, from the good effects of the phenomenon of adaptation. This is because of the margin of security separating the limit of elasticity from that of rupture of metal, a margin that imprudent constructors have attempted to reduce by too great an amount, sometimes with undesirable effects. To appreciate this it is sufficient to witness a test to destruction of a redundant pin-jointed metal frame and see how the stronger members relieve the weaker in an apparently reasoned way.

These new conceptions of reinforced concrete, the results of experiments, had important practical consequences amongst which are the following:

(a) Continuous Beams.—Hennebique, departing from the classical formulæ based on the hypothesis of a homogeneous material, assumed that the sections of a continuous beam near the supports resisted only a part of the bending moment given by these formulæ. To compensate for this, the strength of the beam was increased at midspan and so beams were created with partial continuity whose action depends on the phenomenon of adaptation. Previously condemned by impenitent theorists, the principles on which these beams were designed is now recognised by most official regulations.

(b) Indeterminate Arches.—Theorists of the second stage simply added together as independent phenomena the effects of shrinkage and the linear variations due to changes of temperature, but still ignored the effects of creep, and on this basis concluded that fixed arches of small rise were an irrational solution, sometimes even a dangerous one. This was a return to hinged determinate arches which constituted, in most cases, one of the errors of this stage.

A more profound knowledge of both the separate and interdependent roles of shrinkage and of temperature on the one hand, and of the consequences of creep on the other hand, led to the reintroduction of monolithic hingeless arches of small rise. The principal effects of creep on an arch are: (1) For the dead loads,

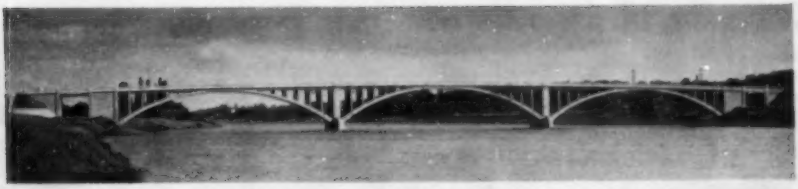


Fig. 4.—Bridge over the River Saône at Tournus.

Fixed arches of 210 ft., 217 ft., and 210 ft. spans. Width 33 ft. Each span comprises two ribs 11 ft. 6 in. wide spaced 10 ft. apart. Built by Entreprise Pierre Pasquet.

Fig. 5.—Bridge over the River Sarthe at Beaumont.

Three-hinged arch; span 267 ft., rise 37 ft. The columns between the arch and the deck are the full width of the bridge. Freyssinet hinges. Built by Entreprise Zublin-Perriere.

Fig. 6.—St. Lucien Bridge, Tunisia.

Span 303 ft. Concrete made with high-alumina cement and cured in a water-jacket. Designed by Henry Lossier. Built by Entreprises Fourre et Rhodes.

to increase the bending moment at the crown and reduce it at the springing; (2) To reduce the effects, both at the crown and at the springings, of shrinkage and of movements of supports. Creep always increases the risk of buckling of arches and domes of relatively small stiffness. In short, to-day's views approach the intuitive views held during the first stage and which were temporarily resisted by insufficiently informed theorists. *Figs.* 1 to 14 show some examples of French construction during the period.

FOURTH STAGE.—During the three previous stages engineers confined themselves in a passive manner to accepting the free natural action of structures. In the fourth stage, however, they sought to impose on structures, by artificial means, a method of satisfying certain conditions. This corresponds, in fact, to

Fig. 7.—Viaduct at Longeray over the River Rhone.
Central arch spans 225 ft. with 195 ft. rise. Built by Entreprise Limousin.

the methods used during the past century by some builders of timber bridges who, by means of wedges, introduced artificial stresses in frames.

In France M. Freyssinet introduced the method of releasing the centering of arches by using hydraulic jacks acting at the crown to force the half-arches apart and upward; this also reduced the stresses caused by shrinkage of the concrete and movements of the supports. M. Batide and M. Caquot arranged the voussoirs of arch bridges in a special manner to achieve the same effects. Finally the writer formed the keystone of an arch by means of a voussoir of concrete made with expansive cement, notably in a bridge of five spans at Laroche, on the railway between Paris and Dijon (*Fig.* 15).

Research was directed also towards the artificial modification of the properties of concrete. In France Considère's hooped concrete increased both the strength and ductility of the material by achieving a state of triaxial stresses under the combined actions of the loads and the corresponding reaction due to the hoops. Augustin Mesnager, inventor of the method of photo-elastic analysis, demonstrated

Fig. 8.—Viaduct over the River Rance at Lessart.
Main arch of plain concrete. Span 274 ft.; rise 41 ft. 6 in. Built by Entreprise Monod.

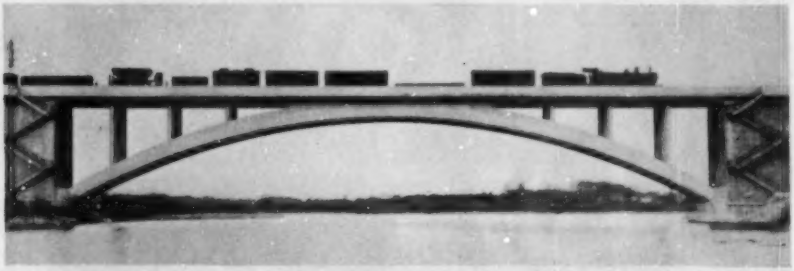


Fig. 9.—Jonnelière Viaduct over the River Edre.
Span 309 ft.; rise 41 ft. 6 in. Built by Entreprise Monod.

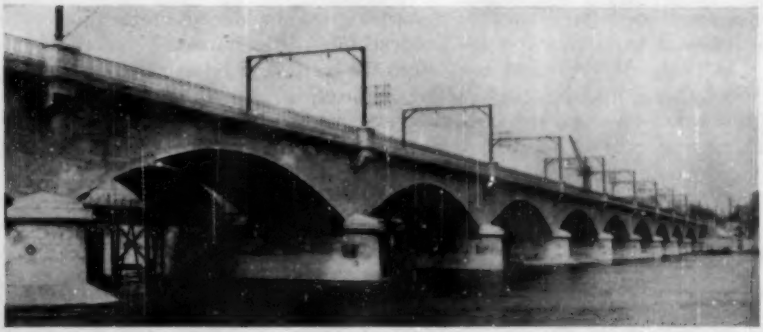


Fig. 10.—Viaduct over the River Loire at Orleans.
Continuous arches with maximum span of 154 ft. Built by Entreprise Fougerolle.

that ceramic elements under hydraulic pressure could withstand forces and deformations greatly exceeding those due to simple axial forces, and these results coincided with those obtained by Föppl with crystals and by Emperger in Austria with cast iron. These investigations led towards prestressed concrete.

Prestressed Concrete.

Prestressed concrete first appeared at the end of the nineteenth century. In principle the idea of prestressing in its most general sense is very ancient. The fisherman who bound his rod to prevent it splitting made use of prestressing, as did the cooper who hooped his barrel, the wheelwright who fitted iron tyres

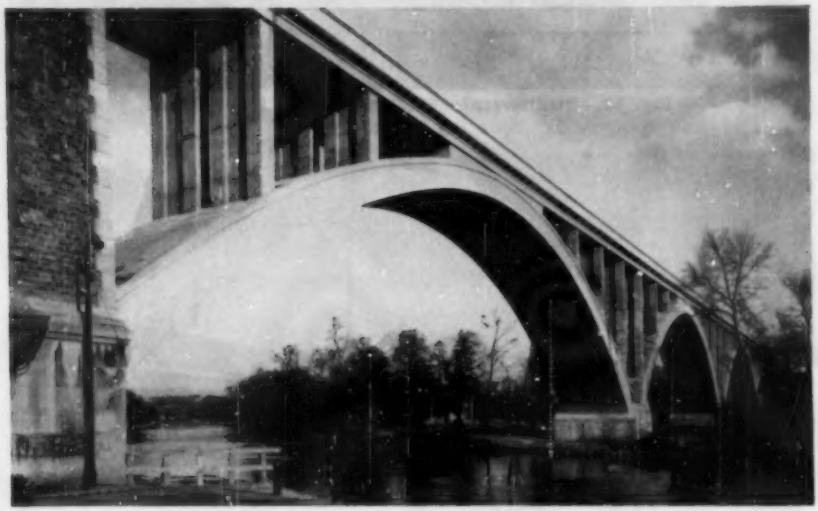


Fig. 11.—Viaduct over the River Rhone at Nogent.
Arch spans of 262 ft., 230 ft., and 223 ft. Built by Entreprise Limousin.

while they were hot, the armourer binding gun-barrels, equally utilised prestressing. Nearer to our own time, half a century ago, Ritter, Rabut, Considère, Dischinger, and others envisaged in many forms the artificial regulation of statically-indeterminate structures. Although mainly of French origin these ideas, received with reserve in France until about 1925, gained ground in other countries, notably in Germany and the U.S.A. Although, mainly due to the rich inventive genius of M. Freyssinet, prestressing appeared to have chosen France as its cradle, we have to acknowledge the debt we owe to those who went before us and whose work is the basis of our modern conceptions.

The invention of linear prestressing of mortar is due in fact to a Berlin builder, Doehring, who obtained a patent in 1888 for small floor elements, reinforced with iron wires tensioned by a screw-jack. The ideas of Doehring, remarkable for their time and more far-seeing than those of many who followed him, represented

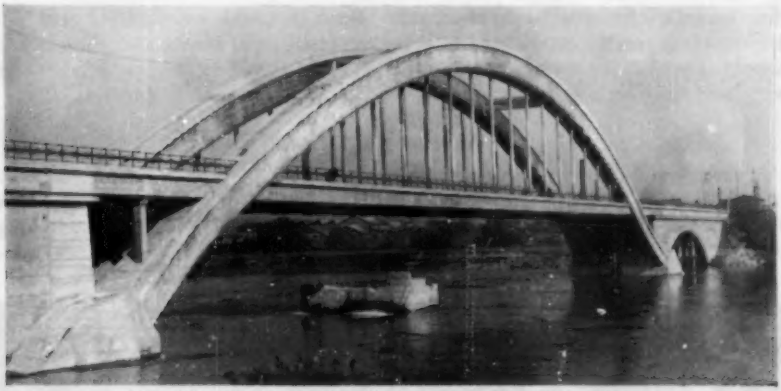


Fig. 12.—Mediterranée Viaduct over the River Rhone.
Span 405 ft.; rise 78 ft.

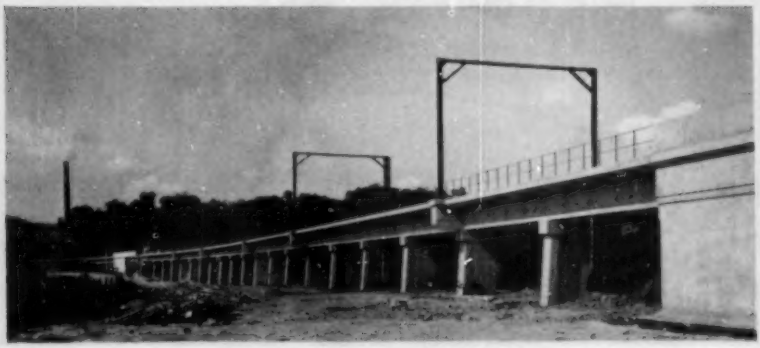


Fig. 13.—Viaduct at Bastide.
Length 3030 ft.; spans 30 ft. and 39 ft. 6 in. Built by Entreprise Fourre et Rhodes.

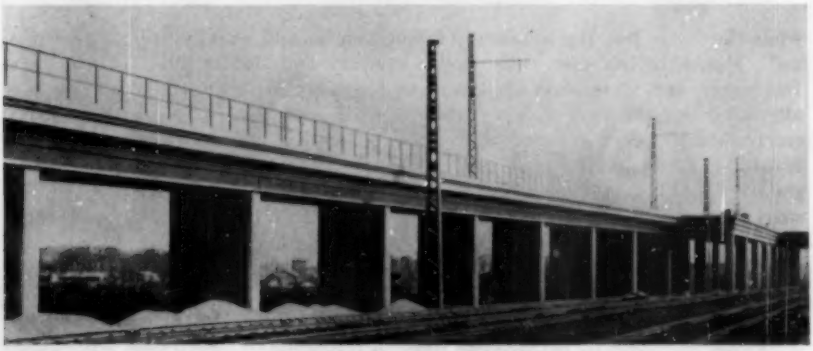


Fig. 14.—Viaduct at Dijon.
Total length 3600 ft. in continuous spans of 39 ft. Built by Entreprise Deschiron.

in a large measure many of our views to-day. In 1923 Emperger introduced the first high-pressure pipes bound with reinforcement so as to impose a circumferential compressive stress exceeding the tensile stress to which the pipe would be submitted. This system, with the addition of a longitudinal pre-compression, is now used in France and in French territories oversea.

M. Freyssinet undeniably has the chief honour of bringing the development of prestressed concrete to the state it has reached to-day. He demonstrated, notably, the necessity to take into account, in determining the prestressing force, the losses due to shrinkage and creep of concrete and the relaxation of the steel. Ignorance of these factors had been the cause of failure of many inventions, for example those of Lund and Koenen in Germany. The work of M. Freyssinet is too well known to require description in this short note.*

Many systems of prestressing were introduced in France following M. Freyssinet's methods; most of them were original only in the method of tensioning the

Fig. 15.—Laroche Bridge.

Railway bridge with five spans of 65 ft. Arches of plain concrete with voussoirs of expansive cement. Built by Entreprise Fourre et Rhodes.

steel, which was achieved in some cases by distorting the wire to a polygonal form by torsion and by the use of wedges, jacks, etc. A particularly interesting method is that of M. Chalos, who uses articulated tubes tensioned by means of a flexible internal element.

Some engineers express doubt as to the exact value of the losses of the prestressing force due to shrinkage and creep of the concrete and the relaxation of the steel. It may be assumed that this loss is a proportion of the original force, more or less arbitrarily decided in advance, for most structures. But in fact this proportion varies with many factors and particularly with temperature. Between a member immersed in water and an element exposed to high temperature this proportion may vary from one to four. It is to reduce the uncertainty of an arbitrary estimate that devices were introduced capable of adjusting the prestress with varying temperatures so that the losses may be compensated for as required, thus ensuring better agreement between calculations and actuality. Moreover, the prestressing cables may be placed so that their replacement is possible without interfering with the use of the structure should an accident occur or should this be

* Illustrations of some prestressed structures designed by M. Freyssinet are given on pages 7 to 12 of this number.

made necessary due to variation of temperature, load, or other causes This method has been used by Dischinger in a bridge at Aue, in Germany, although the medium-tensile steel bars of large diameter that were used may not have had sufficient elasticity and their adjustment might be attended by risk.

Therefore the writer, in the bridge (*Fig.* 17) over the Seine at Villeneuve-St. Georges, near Paris, used flexible cables passing over frictionless rockers which enable the forces to be easily adjusted. Also, in collaboration with M. Charles Berger of Ets. Fourre et Rhodes, methods have been developed which show considerable saving in cost by reducing the twisting of the wires of cables, by simplifying and reducing the size of the anchors and replacing metal by concrete, and particularly by determining the most suitable shape for the ends of the wires. The results of this work will shortly be published.

Summarising, there are now available many solutions which may be classified as follows. (1) Prestressed structures in which the steel is tensioned before casting the concrete, that is pre-tensioning; it may be possible in future to devise methods of adjustment during service for the structures in which such elements are used. (2) Prestressed structures in which the steel is tensioned after the concrete has hardened (post-tensioning), and which may be inspected and adjusted. (3) Self-stressing structures which are stressed by the action of expansive cements; this method was suggested by the writer about 1925 and the cements are made by the French firm Poliet et Chausson.

Pre-tensioning and post-tensioning enable a prestressing force to be achieved which is limited only by the crushing strength of the concrete, whereas the third method is less efficient and is limited by the quality of the expansive cement. Expansive cements are useful in a more restricted field; for example, in many cases self-stressing may be usefully employed in conjunction with mechanical methods of prestressing, notably when it is necessary to impose a relatively lower prestress transversely to the main prestressing.

Certain methods, mainly those due to the German firm of Dyckerhoff &

Fig. 16.—Prestressed Bridge at St. Remy.

Two spans of 105 ft. each comprising eight beams 3 ft. 3 in. apart. Compressive stress in concrete after prestressing, 2130 lb. per sq. in. Built by Entreprises Modernes de Batiment et des Travaux Publics.

Fig. 17.—Villeneuve St. Georges Bridge over the River Seine.

Widmann, are particularly applicable to construction by cantilevering. The bridge over the Rhine at Worms* is an example of this. The system, well known to French engineers, has been used by the writer in a design for a shallow bridge of 208 m. clear span for the Administration des Ponts et Chaussées.

In France, as elsewhere, there are two tendencies concerning the basic principles of prestressed concrete. The first, a rigid view, is that theoretically there should be no tensile stress due to bending in a structure, including the secondary members, lintols, wind-bracing, and so on, so that there is little likelihood of cracks occurring in the concrete. The second, more liberal, view permits small tensile stresses in the concrete and some secondary parts of a "prestressed" structure to be of reinforced concrete. These structures are defined as "partially prestressed", the prestressing being simple or multiple in the sense of being in one or in many directions. If this partial prestressing is carried out in three directions and tensile stresses are not present the result is the same as the total prestressing first described. It may be seen, therefore, that a triaxial prestress gives to a fragile material greatly increased strength and ductility, that is the alterations of the properties of a material which were first mentioned about fifty years ago by Considère, Föppl, and Mesnager, and which were discussed at the beginning of this article. In fact it is unlikely that the two tendencies in question will be opposed in the future.

Between ordinary reinforced concrete and completely prestressed concrete, which are the limits of the actual possibilities, there is a range of intermediate solutions some of which are now preferred, particularly outside France, because they are cheaper. This is notably the case in Germany, as is seen in the examples of the bridges over the Rhine at Ulm and Worms and in other places. In reality there does not appear to be any justification for exaggerating the importance of cracking of concrete due to strain. Even with structures exposed to fumes, gases, or liquids which attack concrete, cracks are really dangerous only (a) when they are wide enough to allow the steel to be attacked, and (b) when the loss of tensile strength in the region of cracking invalidates design assumptions. But long experience has shown that cracks with a surface width not exceeding 0·5 mm. rarely extend to the reinforcement.

Accepting that a partially-prestressed structure is always better, having regard to the smaller risk of cracking, than an ordinary reinforced concrete structure it does not appear justifiable to neglect it in cases in which cracking is admissible. In other words, the choice between reinforced concrete, partially-prestressed concrete, and totally-prestressed concrete need, except in special cases where the absence of cracks is imperative, be a consideration only of cost.

Defects in reinforced concrete structures, as in all other materials, show that

* See this journal for August, 1953.

Fig. 18.—Viaduct over the River Rhone at Voulte.
Prestressed frames spanning 184 ft. Built by Entreprises Boussiron.

in France there has been great improvement between the first and second quarters of the century. In the first period about two-thirds of the defects were the result of poor workmanship and one-third to errors of design. To-day the proportions are reversed. In the beginning the experience of contractors was sometimes insufficient whereas many designers benefited from their association with eminent engineers. Later, there was a more widespread knowledge of methods of construction, but some inexperienced designers. However, the proportion of defective designs decreased because of the greater control of building.

The Future of Reinforced and Prestressed Concrete.

One may ask what will be the future of reinforced concrete and on which factors progress will depend. Ordinary reinforced concrete has stood the trial of time for more than half a century and a great many remarkable structures have been built of the material. Prestressed and partially-prestressed concrete have, for their part, technical and sometimes economical advantages which are incontestable, but the period during which the structures built by these methods have been observed is relatively short. The small margin sometimes allowed between the usual working stress and the elastic limits and stress at failure of high-tensile steel has sometimes caused doubt about the behaviour of such structures with time, particularly structures submitted to intense vibrations or exposed to indefinite repetitions of loads. The possibility of the rusting of the steel should also be considered, particularly if it is protected by grout of doubtful efficiency. It may also be noted that the application of imposed loads does not always have a negligible effect on the stresses in the steel, for example in railway sleepers, and this depends on the care with which the work is done. All these factors have an effect on the long-term behaviour of prestressed concrete.

Self-stressing, which has the practical advantage of not needing mechanical means of application, is limited in its application by the relatively small force exerted by the expansive cements, the first tests of which date from about fifteen years ago. Research is now going on to obtain much greater expansive forces.

In other ways progress is certainly possible in improving the quality of steel for reinforced and prestressed concrete, as well as in deformed bars and anchors. But above all it is the quality of cements to which attention must be devoted. Concrete of low tensile strength is an incomplete material that it is necessary to reinforce or prestress. When we have binders which have some of the qualities now lacking, the use of reinforcement will diminish. Concrete which is more adherent, more ductile, with greater resistance to strain, possessing an expansion greater than its shrinkage may be much more desirable than any improvements in reinforcement. Methods now in use mark but a step, however undeniably glorious, in the art of construction.

GREAT BRITAIN

By F. E. WENTWORTH-SHEILDS, O.B.E.

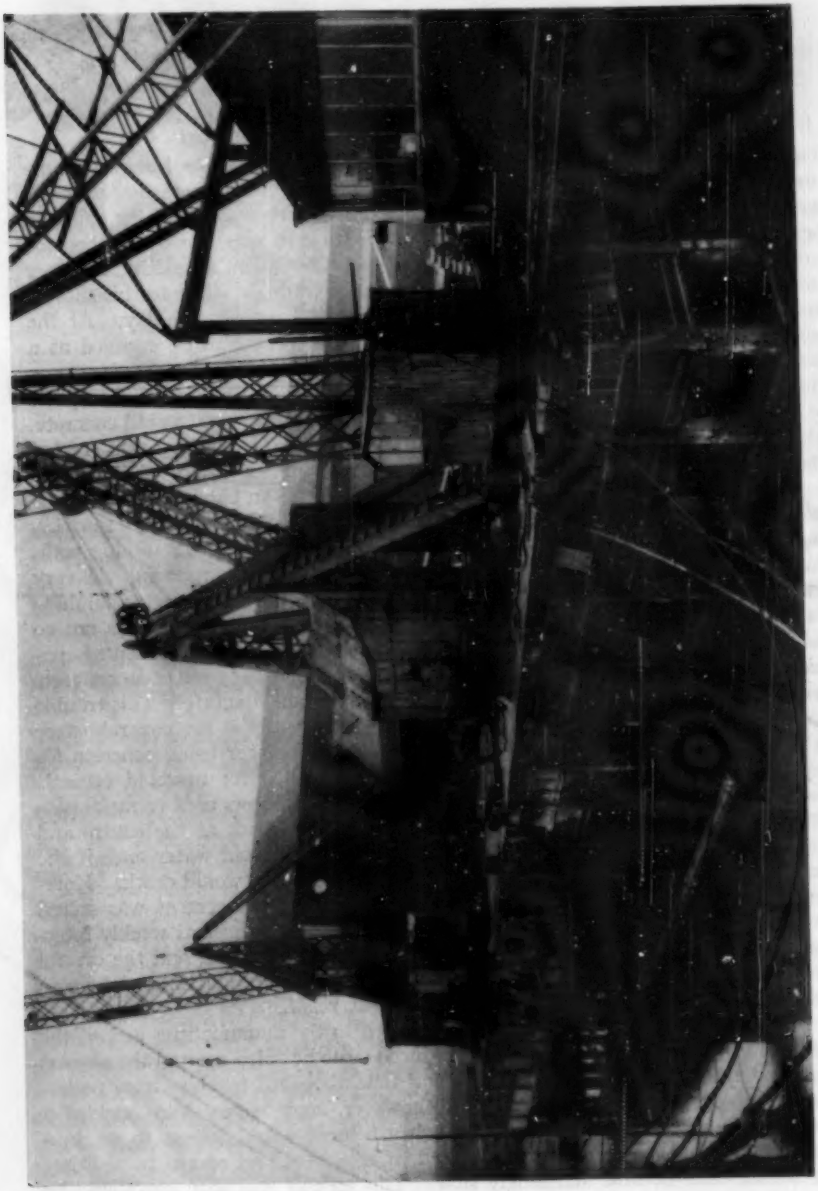
Past President, Institution of Civil Engineers.

Early Marine Structures.

The branch of engineering that involves the use of concrete has seen some remarkable changes since the beginning of the century. Fifty years ago, although we were congratulating ourselves that Portland cement was evidently going to be very useful to the engineer, we little thought that its uses would soon become so diverse and so complicated that, in order to master them, a qualified engineer would find it worth while to devote a year of post-graduate study to this subject under the tuition of a specialist. That is what is happening to-day. At the beginning of this century the writer had the good fortune to be engaged as a young engineer at the Port of Southampton which, from small beginnings, was growing to be a famous gateway of England, and which was one of the first ports to adopt what was then regarded as a weird novelty, namely reinforced concrete. The first maritime structure in reinforced concrete in this country was erected at Southampton in 1899, and is still giving good service—more of this later.

At that time, and during the previous fifty years, an enormous amount of railway and dock construction had been carried out, in this and other countries, in which concrete was freely used. Most of the plain concrete retaining walls we see to-day belong to this period. Almost all were highly successful. A very few failures occurred, generally due to chemical action of sea-water or sulphate water on "unsound" cement. The chemistry of Portland cement was not so well understood as it is now, and occasionally a consignment was received containing uncombined lime. The effect of sea-water or sulphate water on concrete made with such a cement was to cause it to swell and disintegrate. This trouble might occur months after the concrete had set, especially if the concrete were ill proportioned and consequently permeable. The engineer using concrete for maritime works was therefore constantly on the watch for unsound cement. Before Le Chatelier produced his test for soundness, engineers used to make pats of neat cement, about 3 in. diameter and about ½ in. thick at the centre and diminishing to a feather-edge; these were immersed in cold water and, if the cement contained an excess of uncombined lime, the edges would crack. Moreover on important works, as an additional precaution, the cement was stored on a dry floor and turned over by men with shovels three times at weekly intervals. The introduction of the rotary kiln and of finer grinding, and the careful chemical control introduced by the manufacturers about this time, did away with the necessity of this process—to our great relief.

The rotary kiln was an immense boon both to the manufacturer and to the user of Portland cement, as it not only reduced costs but also ensured the cement being calcined at an even temperature and thus abolished troubles from underburnt and overburnt cement. At first, however, some rotary kilns yielded a cement which was "flash" setting. Such a cement would appear to set in a matter of seconds instead of minutes and, if re-wetted and placed in position, the setting-time became alarmingly slow. This trouble was soon conquered by controlling the quantity of added gypsum.



Jetty at Southampton. Built in 1899.

It may be said, therefore, that when reinforced concrete began to be used in this country the manufacturers were able to supply a good and reliable cement, and that this has contributed largely to the success of this new material. In the early days, however, there was a good deal of prejudice to overcome. Engineers who had used concrete in massive breakwaters and retaining walls had great confidence in it, but they were nervous of using it in comparatively thin sections containing steel bars with a cover of only an inch or so of concrete to prevent the steel from rusting ; indeed some of the early experience with the new material showed that their fears were not altogether groundless.

The first of the maritime structures built in reinforced concrete at Southampton was a jetty consisting of a reinforced concrete deck measuring about 100 ft. by 40 ft. on piles of the same material. It was erected in 1899 at a shipyard which in 1906 was acquired by Messrs. John I. Thornycroft & Co., Ltd., the famous builders of naval destroyers, and has been in constant use throughout its long life. It was designed and supervised by Hennebique of Paris. Its equipment includes a crane with a capacity of 60 tons, which is used to lift boilers and other heavy loads on to ships lying alongside. The foundation of the crane is independent of the jetty, but it will be readily understood that its use causes much hard wear on the jetty. In spite of this the writer found on a recent visit that the structure was in excellent condition and showed no sign of deterioration.

A few years later (1902) Town Quay was built at Southampton Docks by the Railway Company which then owned them. This, too, was a reinforced concrete structure measuring 360 ft. by 20 ft., and about 34 ft. high. It was equipped with travelling grab-cranes which transferred coal from South Wales colliers alongside the jetty to barges on the other side. The barges were subsequently towed to ocean-going steamers, where the coal was transferred to their bunkers. The jetty consisted of a reinforced concrete deck carrying the cranes and resting on piles of the same material, stiffened with longitudinal, transverse, and diagonal bracing. In a very few years this jetty, though apparently well built, showed signs of serious decay. The piles and bracing below mean tide-level were quite good ; but above that level longitudinal cracks appeared in the piles, braces, and deck-beams. These cracks followed the lines of the main reinforcement bars and were obviously due to the steel rusting under the concrete cover and bursting it off. The deterioration became so serious that the jetty was pronounced unfit to bear the weight of the cranes, and it was strengthened with new piles and decking.

Other reinforced concrete jetties at Southampton in the early years of this century suffered similar deterioration though, fortunately, not to the same extent. Mr. J. P. M. Pannell, Engineer of the Harbour Board, gave a most interesting paper * at the Institution of Civil Engineers describing how such deterioration was arrested at the Southampton Town Quay by means of gunite. This work has been very successful. The writer was given an opportunity of seeing it recently and found that, although the gunite is now nearly twenty years old, it is in excellent condition. Readers of Mr. Pannell's paper will realize, however, that the success of gunite involves great care and skill in carrying out the work.

Similar deterioration occurred at other ports, and roused engineers who

* "Cement Gun Repairs to Maritime Reinforced Concrete Structures, with Special Reference to the Town Quay, Southampton." I.C.E. Maritime Paper No. 2. 1945-46.

Town Quay, Southampton: Showing Deterioration.

Town Quay, Southampton: After Repair.

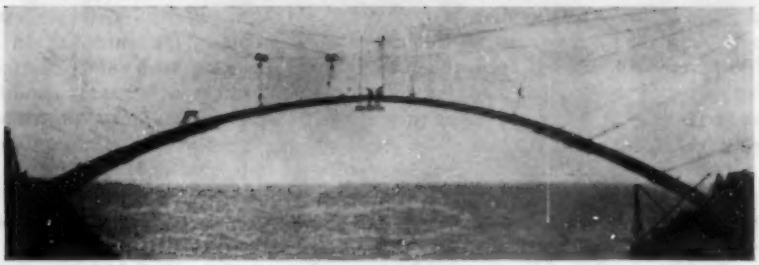
suffered by it to investigate the causes of the trouble and the means of preventing it. One of the first tasks of the Concrete Institute (which was founded in 1909 and afterwards became the Institution of Structural Engineers) was to appoint a committee to deal with this question, and its report appeared in 1911. Later, in 1935, the Sea-action Committee of the Institution of Civil Engineers published the results of some very useful research work which had been carried out for them by the Building Research Station, D.S.I.R., and which indicated the precautions necessary to prevent deterioration of concrete and reinforced concrete in sea-water.

The earlier investigators were inclined to ascribe the trouble to electrolytic action; and indeed, in the case of the second jetty referred to in the foregoing, electrolytic action was, if not the sole cause, a very important contributory. The electric cranes which travelled on the jetty were worked by direct current at 480 volts on the three-wire system, the neutral wire being earthed to a steel-girder bridge at one end of the jetty. It was found that considerable amounts of electricity passed through the reinforcement from the bridge to the sea, and that this largely—but not entirely—accounted for the corrosion. The report of the Sea-action Committee ascribes the rusting of the reinforcement to the permeability of the concrete, and probably every port engineer who has experienced this trouble will agree with this view. It is true that reinforcement in piles and bracing below mean tide-level rarely suffers in this way, even though covered only by the same permeable concrete that fails to protect it at a higher level, but no doubt this is because air cannot reach steel that is always under water, even if the cover of concrete is permeable.

Thornycroft's jetty, which, as already stated, is 56 years old and still in excellent condition, was made with a very "dry" concrete, and the old-fashioned "ball" test was constantly applied during its construction to ensure the stiffness of the concrete. On the other hand, some of the later structures at Southampton were deliberately made with a "rather wet" mixture. It was considered that such a mixture, being more workable than a dry one, would be more likely to pass freely between the reinforcements and thus closely surround them. This, of course, is doubtful because a wet mixture tends to shrink away from the bars when setting, and we now realize that a high water-cement ratio involves a high proportion of air voids and thus produces a weak and permeable concrete. At that time we were fearful that, with crowded steel and a "dry" concrete, even careful ramming might fail to prevent honeycombing. The introduction of vibration has solved this problem, as it has enabled the use with safety of much drier mixtures than formerly, giving greater strength and greater impermeability. The success of the gunite covering at the Southampton Town Quay, previously mentioned, is no doubt accounted for by the close adhesion and impermeability of this material. Incidentally, it is interesting to note that in those early days we were eagerly in search of a method of quickly testing the permeability of the concrete structures we had erected. The new ultra-sonic method of testing (see this journal for November, 1954) seems to have solved this problem.

The introduction of prestressing has opened up another new field for concrete, and who knows what may follow? It is good to remember that the difficulties and failures from which reinforced concrete suffered fifty years ago and the persistence with which they were investigated and overcome have made it possible to extend the usefulness of this material.

Footbridge at Mizen Head, Ireland. Built in 1909.



[Span 172 ft. Height above sea level 150 ft. Footpath 4 ft. 6 in. wide. Ribs precast in four parts on the shore and placed in position with the aid of a cableway. Deck and hangers cast in place.]

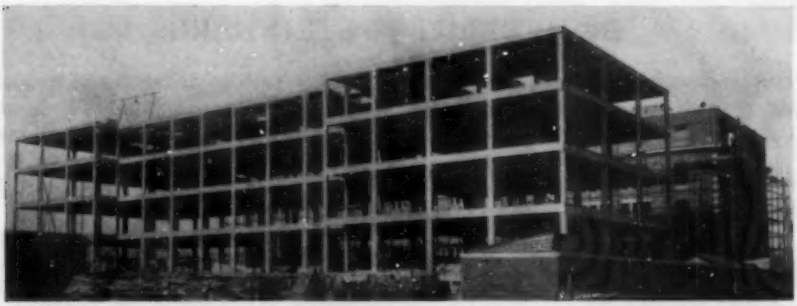
GREAT BRITAIN

By HERBERT E. STEINBERG

For no especial reason that I can think of, except perhaps advancing years and the passage of time, I have been asked by the Editor to write a short note on the early development of reinforced concrete in this country. First, I think one should congratulate and thank those who so long ago foresaw the development of structural concrete and had enough courage to start a technical journal to deal with it.

I have not been connected with reinforced work for a full fifty years, having joined the Considère Company in 1909 when reinforced concrete had already been established in England for nine or ten years. It is difficult to cast one's mind back to the early days, but a few features stand out strongly. One is the undoubted antagonism of most consulting engineers, and another is the curious fact that H.M. Office of Works and the Post Office authorities, with the late Sir Henry Tanner as architect, were among the first to adopt reinforced concrete for some of their big new buildings. The General Post Office building off Newgate Street, London, was built by Messrs. Holloway Brothers (London), Ltd., in 1909, and although the details of the design would probably nowadays be thought to be unacceptable, nevertheless the building has stood extraordinarily well, and the explosion of a bomb nearby caused no serious damage to it. The floor load was established by weighing the loads on the floors of an existing similar building and adopting these as the loads for the new building. These worked out at 1 cwt. per square foot on the ground floor and ¾ cwt. per square foot on the upper floors, which are very much lighter than they would have been had some conventional loading for a similar building been adopted. The stresses, particularly

General Post Office, London. Built in 1910.
Reinforced concrete frame with Portland stone elevations. Capacity 8,000,000 cu. ft.



Store at Birmingham for H.M. Office of Works. Built in 1907.

Two of these buildings were erected by 1908, and three more were built later. Each building is 203 ft. long by 65 ft. wide and 60 ft. high. The reinforced concrete frames were faced with brick and stone.

in the columns, must be exceedingly high, and I imagine no notice was taken of the effect of the bending of the columns produced by the deflection of the beams. Although the Post Office adopted reinforced concrete so early, some of the other Government departments were definitely hostile.

In the early days there were no London County Council regulations or codes of practice for reinforced concrete, and designers could use only what they conceived to be sound calculations. It is interesting to look through some of the early text-books, and it is astonishing to find that many of the writers were much in advance of their time. Tedesco (1909) produced a valuable book dealing with nearly all the applications known at that time, many of the details of which could still be classed as modern. Professor Mörsch published in 1905 a comprehensive book in which were described many of Considère's experiments, and in addition the results of a large number of tests made by Messrs. Wayss & Freytag were carefully prepared and excellently recorded. This book is still worth occasional reference.

M. Considère wrote an early book giving the results of his many experiments, and this was translated into English and published in 1906. It describes, amongst other examples, the test to destruction of an experimental bow-string bridge in which part of the top chord was made weaker than the rest in order to establish the value of helically-reinforced struts. Unfortunately the bridge did not break in the way anticipated, but failed near one end at a load considerably greater than that which was thought to be the maximum. A great deal was learned from these tests, and the now generally-accepted methods of calculation were, I believe, due to Considère. M. Magny (1914) published a comprehensive book dealing with the theory of design and giving many examples of reinforced concrete bridges, silos, reservoirs, pile foundations, etc.

In this country the undoubted leaders were Marsh and Dunn, who published a large volume in 1906 and a smaller manual in 1908. This book gives many tables of suitable reinforcement for members with various loads and spans, but they do not seem now to be of much use or interest; many of the illustrations dealing with hollow concrete block-work could, however, be classed as modern.

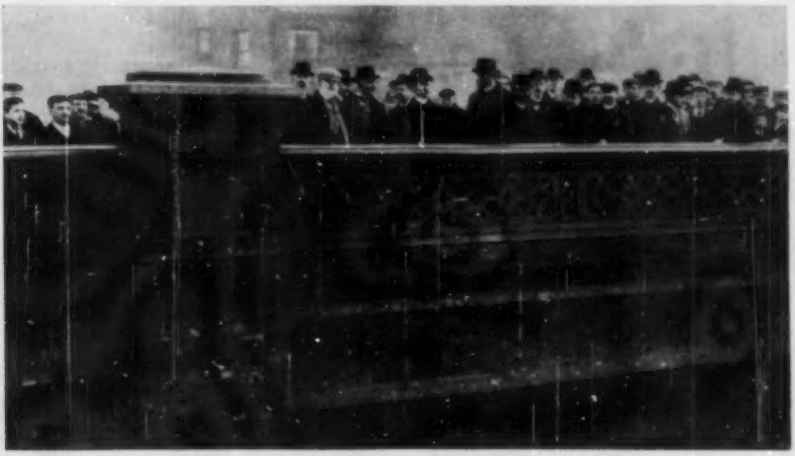
Other text-books in English followed at frequent intervals, but concrete design did not really change or advance very much (in spite of the enormous improvement in the quality of cement and the strength of concrete) until M. Freyssinet developed prestressed concrete, which opened up new possibilities and new avenues of thought. M. Freyssinet's ingenuity and adaptability enabled him to produce appropriate solutions to many different types of problem, and his work has done more than anything to change our ideas on the design of concrete structures.

Returning to early work, there was quite an enthusiasm for what were known as " deformed bars ". Some of these still survive and, with the introduction of higher stresses, have proved their usefulness, but others, like the Kahn bar, have completely disappeared.

A word should be added on the improvement in concrete during the past fifty years. About 1910 test cubes at three months with a rich mixture were expected to have a compressive strength of 2400 lb. per square inch, and this was by no means always achieved. Nowadays, although such very high strengths are not usually required except for prestressed work, crushing strengths of 6000 and 7000 lb. per square inch are quite common, and anything below 4000 lb. per square inch is thought to be almost dangerous.

The plastic property of concrete was realised for some years before Dr. Oscar Faber read a paper on the subject at the Institution of Civil Engineers in 1927. Although the members which he tested were smaller than the dimensions of ordinary reinforced work, his investigation undoubtedly drew more attention to this property of concrete and in the design of some structures it is very desirable that full cognizance should be taken of plastic flow and creep.

It may be useful to add a word on calculations for reinforced concrete. Unlike many branches of engineering, such as electrical and hydraulic, calculations for reinforced concrete can seldom be really accurate owing to the number



Cleveland Street Bridge, Hull. Built in 1902.

of assumptions that have to be made, and the changes in the behaviour of the material when subjected to different stresses. In 1939 the Department of Scientific and Industrial Research issued a technical paper on " Moment Redistribution in Reinforced Concrete " as the result of tests made in collaboration with the Reinforced Concrete Association to determine the difference between the theoretical stresses calculated by the ordinary methods and those realised in practice. Many of the results were surprising and, in reference to continuous beams, are summed up by the following paragraph from the Report : " The concrete at the support continued to carry load in an apparently undistressed condition long after the load calculated to produce a maximum fibre stress equal to the cube strength of the concrete. At the same time the widths of the cracks that appeared were small, so that no reference to cracking need be made when considering redistribution of moments resulting from creep of the concrete. The deflections of the beams were of the same order as those in the tests with a deficiency of continuity steel." The known inaccuracy of many calculations for reinforced concrete do not matter very much, as the calculations are nearly always on the safe side and the actual stresses are invariably below those calculated from theory. Such failures as there have been (and these are very few) seem nearly always to have been due to bad general design or bad workmanship, and not to the detailed calculations for the reinforcement. In view of the early ignorance of the material and the poor quality of the concrete in many of the early structures, it is surprising how little trouble has been experienced.

Reinforced concrete has now been used long enough to give some estimate of its probable life, and this experience shows how essential it is to have almost surplus cement in concrete that is to be exposed to the weather, and particularly when it is exposed to sea-water. Considère stated many years ago that concrete for maritime work should contain 7¼ cwt. of cement per cubic yard, and work done to this specification has behaved exceedingly well, whereas other work in similar positions with a 1 : 2 : 4 mixture is porous enough for moisture to penetrate the concrete and corrode the reinforcement, which, in consequence, rusts as well as splits the concrete cover.

In the very early days the main argument for the use of reinforced concrete was its cheapness. Conditions have now changed, and although it is still usually cheaper than any other material of construction, the most important argument in favour of reinforced concrete should now be its permanence, and to achieve this only the best workmanship and the best materials should be permitted.

U.S.A.

By CHARLES S. WHITNEY

PRESIDENT, AMERICAN CONCRETE INSTITUTE.

As President of the American Concrete Institute, and one of the many friends in America of "Concrete and Constructional Engineering," it is a great privilege and pleasure to send greetings on the occasion of its fiftieth anniversary and to express appreciation of its great contribution to the emergence of concrete as a most important component of modern construction. Having had for most of the past fifty years a great interest in this development, the writer hopes that he will be forgiven if the selection of the subject matter of this paper is greatly influenced by his own practice and his American point of view. The last half-century has had peculiar significance in the field of concrete. The first convention of the American Concrete Institute was held in 1905. The first edition of Taylor and Thompson's "Concrete Plain and Reinforced", the first important American standard text-book on the subject, was written in 1905. The first report of the Joint Committee on Concrete and Reinforced Concrete was then in preliminary form and was completed in 1909. There was then a considerable body of literature on concrete in English as well as other languages.

Some Early Successes and Failures.

In fact it can be said that fifty years ago concrete was a success and many outstanding structures of reinforced concrete had already been built. They were built by men of extraordinary ability and ingenuity, basing their designs on their own judgment resulting from their individual research and experience. From this experience, standards of design and construction practices were gradually developed. During the early period many engineers and contractors without adequate ability were tempted by the new material to build structures that later proved to be unsatisfactory. One such structure built in 1909, before building codes for the regulation of reinforced concrete were issued, collapsed a few years ago after about forty years of service, killing twelve men. It was found that the concrete had a compressive strength of about 700 lb. per square inch, and that the design was also faulty. The slabs were designed for a reasonable floor load, but the beams, girders, and columns were progressively weaker. A column had failed under a load of about 100 lb. per square foot applied to the entire area supported by it. The building's occupancy had recently changed and it was, for the first time in its life, subjected to a full uniform load. Previous concentrated loading had not indicated general weakness. There were also many faulty structures built, which in spite of their weakness have given remarkable service.

Much concrete work done fifty years or more ago appears equal in both design and execution to that of the best of recent years. Two such examples which the writer had the pleasure of examining recently are Hennebique's bridges at Chatellerault in France and at Rome in Italy. Both are in service and appear to be in excellent condition (*Figs.* 1 and 2). Before 1900 Hennebique had designed and built more than a hundred bridges, and a total of over 3000 structures of concrete.

Fig. 1.—Bridge at Chatellerault, France.
Built by Hennebique in 1899.

The bridge over the river Vienne at Chatellerault, completed in 1899, has three very flat arches of 40, 50, and 40 metres respectively. The rise-span ratio is less than 1 to 10, and the depth of the arch ribs at the crown is about one-hundredth of the span. Hennebique's bridge over the river Tiber in Rome, finished in 1911, with a clear span of 100 metres, is one of the most remarkable structures ever built. It appears as an arch of very low rise, formed by a curved slab 8 in. thick at the centre of the span, increasing to 20 in. at the springing. However, longitudinal stiffening walls, also 8 in. thick, integral with the arch and roadway deck cause the span to act as a box-girder which is fixed at the abutments to resist the cantilever moments. The rise is so small compared with the span that true arch action is practically eliminated by rib shortening. An examination of the bridge failed to reveal either expansion joints or cracking. The mildness of the Roman climate can account for only part of this excellent behaviour. An interesting feature of both of these bridges is that they have soffits formed by slabs 8 in. thick, tying together the shallow arch ribs. This is a precedent for modern long-span thin-shell arched roofs.

The Ultimate-load Method of Design.

The publication in the U.S.A. of the Joint Committee Report in 1909 supplied a standard for reinforced concrete design in the United States and formed a much-needed basis for building code regulations. Previously many different methods were used in design based on assumptions of parabolic, rectangular, trapezoidal, or triangular stress distribution. The Report recommended the use of the so-called straight-line theory, which is still in general use.

The writer will not attempt to discuss the many important developments of the last fifty years, but will confine his remarks to some current projects in the United States in which he is particularly interested. One of these is the revision of codes to permit the use of the ultimate-strength method of design, which is more realistic and economical than the " straight-line " method. Simple formulæ

Fig. 2.—Bridge over the River Tiber, Rome.
Built by Hennebique in 1911.

have been derived to predict the actual strength of concrete members much more accurately. These have been verified by tests and, with suitable load factors, form a rational basis for design. It is the writer's opinion that the time has arrived when concrete can be considered as a reliable engineering material, in the same way as steel, and extravagant factors of safety, greater than those for steel, are not needed. The recommended ultimate-strength equations therefore contain no factor for variability of the strength of concrete, but assume that in the structure it will be not less than f'_c (the compressive strength of 6-in. or 12-in. cylinders or cubes on which the design is based). It is not intended that the method be used without adequate control of the concrete.

Committee No. 214 of the American Concrete Institute has just submitted a report entitled " Evaluation of Results of Compression Tests of Field Concrete ", to be published soon, recommending a method of control of the strength of concrete, which after discussion will be presented as a standard. It provides that the concrete mixture shall be designed for a strength greater than the f'_c assumed in the design of the structure by an amount depending on the accuracy of the control on the site. To do this, a check must be made on the coefficient of variability of the strength of the concrete as affected by all factors. The increase of the design strength over f'_c will depend on the coefficient of variation of the concrete. This increase may normally amount to 15 to 20 per cent., but the method will permit the concrete maker to take advantage of accurate control and possibly save cement without reducing the strength below that assumed in the design.

An analysis of tests of steel reinforcement bars shows a coefficient of variation which is comparable with that of well-controlled concrete. The bars normally have an average strength well over that specified. The steel and the concrete in a reinforced concrete structure should be put on a similar basis. The present codes based on the " straight-line method " provide a much greater factor of safety against failure of the concrete than failure of the steel. This is uneconomical and

indefensible in the present state of the art of concrete making. Several countries have already adopted ultimate-strength design methods which correct this error.

Because of the basic importance of this subject the writer is taking the liberty of quoting from the report of the Joint Committee of the American Society of Civil Engineers and the American Concrete Institute on Ultimate Strength Design, the sections on the reasons for designing on the basis of ultimate strength and on load factors. This report has just been completed, and has not yet been approved formally by either society.

"REASONS FOR ULTIMATE STRENGTH DESIGN.—The advantages resulting from design of structures for ultimate strength may be summarized as follows:

"(*a*) As ultimate load is approached stress and strain are not proportional. Therefore, the elastic or straight-line theory does not give a reliable prediction of the ultimate strength of a section. In some circumstances, the ultimate strength may be more than 50 per cent greater than that computed by the straight-line theory. It follows that the actual factor of safety cannot be determined by the straight-line theory. This deficiency is eliminated by ultimate-strength design.

"(*b*) Dead load is a determinate quantity that generally remains unchanged during the life of a structure, but actual live loads are less predictable quantities beyond the designer's control. Therefore, it is unreasonable to apply the same load factors to dead and live loads. Ultimate-strength design conveniently permits the use of different factors which result in a more uniformly consistent factor of safety for live load.

"(*c*) Conventional column design is a modified ultimate-strength procedure, whereas the straight-line theory is used for design for simple flexure. It is unavoidable, therefore, that various inconsistencies occur in the design of sections subject to both axial load and bending. Designing all types of members on the basis of ultimate-strength results in consistency in the design procedures.

"(*d*) A better evaluation of the critical moment-thrust ratio for members subject to combined bending and axial load is obtained by ultimate-strength design procedure. In many structures, as arches and multiple-story frames, the thrust may be due largely to dead load while moment is created primarily by live load. By the use of different overload factors for each type of load, the ultimate-strength procedure permits consideration of an increase in live load (and thereby moment) without a corresponding increase in the dead load or thrust. The combination resulting from this consideration may be more critical than that produced by the same increase in both dead load and live load.

"(*e*) For prestressed concrete it is necessary that design recommendations include investigation of ultimate strength to determine the factor of safety since, at high loads, stresses do not vary linearly. The straight-line theory is therefore not applicable, so the ultimate-strength theory must be used.

"Load Factors: The following terms are used in the load-factor equations:

U = ultimate strength of section.
B = effect of basic load consisting of dead load plus volume change due to plastic and elastic actions, shrinkage and temperature.
L = effect of live load plus impact.
W = effect of wind load.
E = effect of earthquake forces.
K = load factor equal to 2 for columns and members subjected to combined bending and axial load, and equal to 1·8 for beams and girders subjected to bending only.

"Members should be proportioned so that: (1) They will be capable of carrying without failure the critical load combination given below, thereby ensuring an ample factor of safety against an increase in live load beyond that assumed in design; (2) The strains under working loads will not be so large as to cause excessive cracking. These criteria are satisfied by the following formulæ:

" For those structures in which, due to location or proportions, the effects of wind and earthquake loading can properly be neglected :

$$U = 1{\cdot}2B + 2{\cdot}4L \quad . \quad . \quad . \quad . \quad . \quad (I)$$
$$U = K(B + L) \quad . \quad . \quad . \quad . \quad . \quad (II)$$

" For those structures in which wind loading should be considered :

$$U = 1{\cdot}2B + 2{\cdot}4L + 0{\cdot}6W \quad . \quad . \quad . \quad . \quad (Ia)$$
$$U = 1{\cdot}2B + 0{\cdot}6L + 2{\cdot}4W \quad . \quad . \quad . \quad . \quad (Ib)$$

$$U = K\left(B + L + \frac{W}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad (IIa)$$

$$U = K\left(B + \frac{L}{2} + W\right) \quad . \quad . \quad . \quad . \quad . \quad (IIb)$$

" For those structures in which earthquake loading should be considered, substitute E for W in the preceding equations. In case there is doubt as to the importance of wind or earthquake loading, it can be tested by making a trial calculation using these equations."

It should be noted that while ultimate-strength formulæ * predict ultimate strengths accurately according to tests, those recommended for design controlled by failure of the concrete are discounted about 10 per cent. to prevent sudden failure of the concrete. This is not uneconomical, because it is usually not practical to provide so much reinforcement that failure will occur as a result of compression of the concrete due to bending of the member.

Modern Structures.

Refinements in methods of design and of control of the quality of concrete have encouraged the use of reinforced concrete for more and more important structures. In the New York area, where not many years ago tall buildings invariably had structural steel frames, concrete buildings are now built more than twenty stories high ; in some South American cities their height exceeds thirty stories.

For fire-resisting buildings, reinforced concrete construction now tends to be

Fig. 3.—Hangar at Chicago, Ill., U.S.A.

* " Plastic Theory of Reinforced Concrete Design ", by Charles S. Whitney. Transactions, American Society of Civil Engineers, Vol. 107 (1942), p. 251.

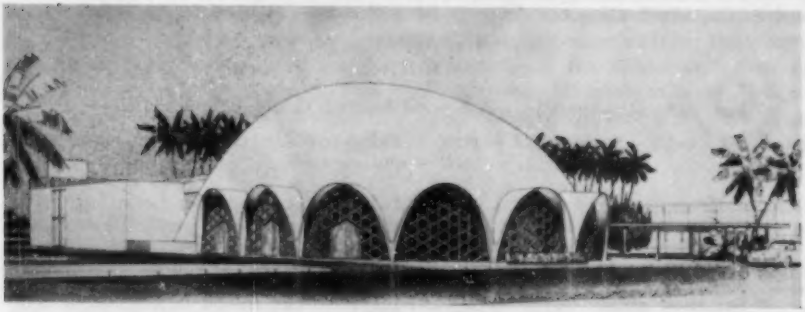


Fig. 4.—Temple Beth Sholom, Miami Beach, U.S.A.

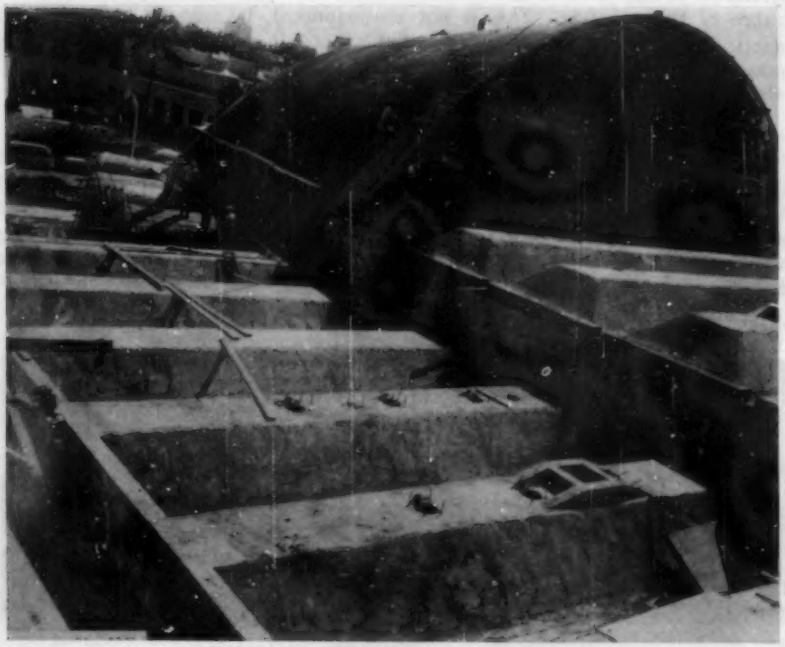


Fig. 5.—Temple Beth Sholom, Miama Beach, U.S.A.

more economical than structural steel. Thanks to thin concrete shells, this is true even of long-span roofs where structural steel was prevalent until recently. The latest trend in long-span concrete roof construction will be illustrated by several designs developed by the writer's firm.

Fig. 3 shows a twin-span hangar built in Chicago for Trans World Airlines. The clear spans are 270 ft. The depth of the ribs at the crown is about one-eightieth of the span. The shell is generally 3½ in. thick.

The Temple Beth Sholom (Mr. Percival Goodman, architect), recently completed at Miami Beach, Florida, has several interesting features. The main structure (*Fig.* 4) is a half-dome with a conical extension. The entire dome has

Fig. 6.—Kresge Auditorium, Cambridge, Mass., U.S.A.

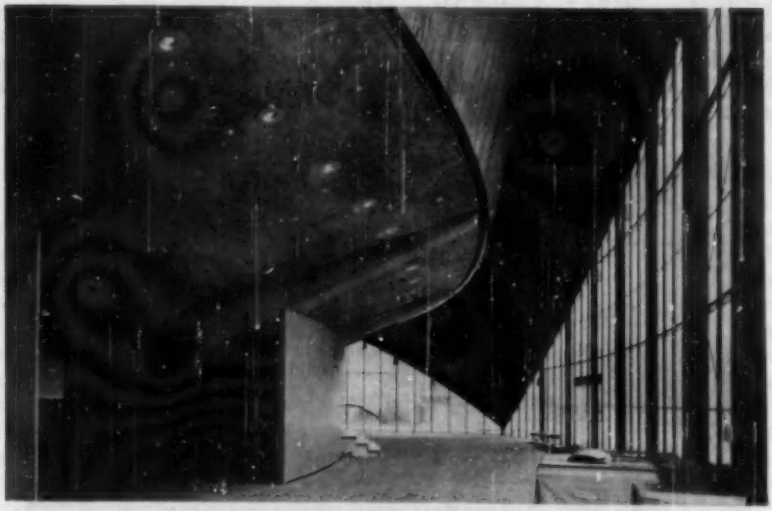


Fig. 7.—Kresge Auditorium, Cambridge, Mass., U.S.A.

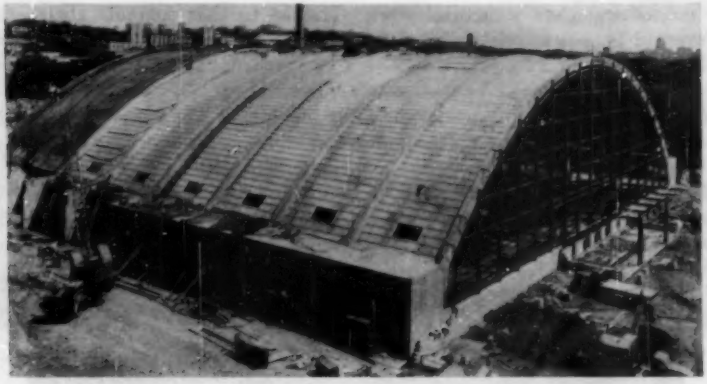


Fig. 8.—Athletic Practice Building, Madison, Wis., U.S.A.

a thickness of 4 in. of lightweight concrete except at the doorways. This thickness is somewhat more than is required for structural purposes, and was used to provide the desired thermal properties without separate insulation. The roof surfacing will consist of a plastic compound of suitable texture, colour, and durability. The assembly hall and lobby are roofed by a corrugated lightweight slab spanning 80 ft. and 40 ft. respectively (*Fig.* 5). The 40-ft. span is 4 in. thick throughout. The 80-ft. span has typical 3½-in. webs (the inclined slabs) with top and bottom flanges 5½ in. thick at the centre.

Figs. 6 and 7 illustrate the unique roof of the Kresge Auditorium at Massachusetts Institute of Technology (Messrs. Eero Saarinen & Associates, architects) recently completed in Cambridge. It consists of a concrete shell in the form of a spherical triangle, one-eighth of a 224-ft. sphere, supported on three steel castings about 160 ft. apart. The dome is 3½ in. thick in its central part and averages 4·8 in. including haunches and edge-beams.

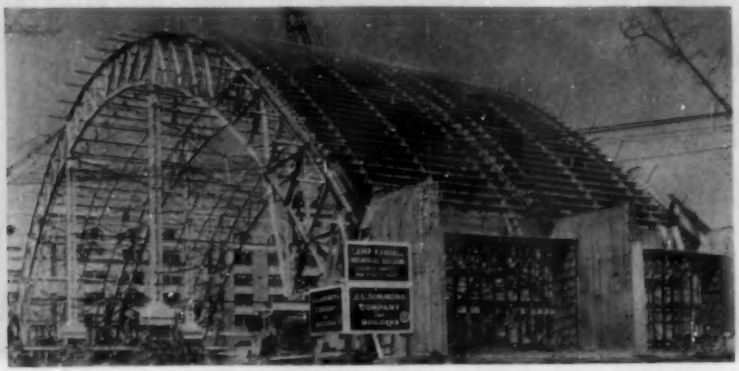


Fig. 9.—Falsework for Athletic Practice Building, Madison, Wis., U.S.A.

A building for athletic practice shown in *Fig.* 8, which will provide an open floor 200 ft. wide and 400 ft. long, is now under construction at the University of Wisconsin in Madison. The end walls will be aluminium panels on a steel frame with limestone trim at the base. Comparative preliminary estimates indicated that the cost of timber arched trusses, unfireproofed arches composed of rolled-steel beams, and reinforced concrete arched shell construction would be very nearly the same. On this building the contractor has elected to use steel arched falsework with timber joists and lagging, instead of all-timber falsework, because of greater ease of moving and greater salvage value (*Fig.* 9). Since it is used seven times, the cost per square foot of building is not great.

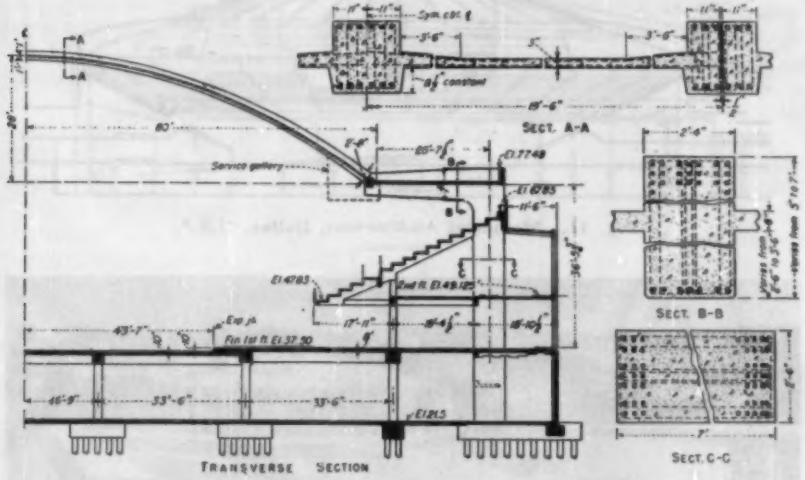


Fig. 10.—Memorial Auditorium, Syracuse, N.Y., U.S.A.

In the design of auditoria, the Onondaga County general-purpose war memorial building in Syracuse (Messrs. Edgarton & Edgarton, architects) is a unique arrangement of concrete shell construction. To keep the roof of the auditorium as low as possible and at the same time provide the desired clearances over the balconies, the arched shell is supported on cantilevered brackets. This arrangement (*Fig.* 10) is economical because it lowers the thrust-line of the arches and reduces the moment at the base of the piers. The balance of the bending moments on the piers is indicated by the fact that there was no appreciable lateral movement of the ends of the arches when the falsework was removed. At that stage the lateral thrust from the cantilevered piers was equal to the thrust of the arches due to the dead load. The span of the roof is about 210 ft. The foundations are on piles in deep soft clay. Horizontal thrust on the footings is eliminated by ties through the ground floor. Estimates indicated thin shell concrete construction to be considerably cheaper than a rigid-frame steel roof.

This arrangement of cantilevered concrete shell has recently been applied for

the first time to the 300-ft. dome of the Dallas Memorial Auditorium (*Figs.* 11 and 12) now under construction in Dallas, Texas (Mr. George L. Dahl, architect). In this case, thirty-two cantilever frames are equally spaced around the circumference of a circle and support a dome of 204 ft. diameter. The dome is formed by sixteen triangular thin shell segments stiffened by ribs and separated by expansion joints. The segments meet at a compression plate of 22 ft. diameter at the crown, 92 ft. above the floor. The central plate will be supported on a tower while the triangular segments are concreted successively in opposite pairs to maintain a balanced condition. This permits the repeated use of movable falsework

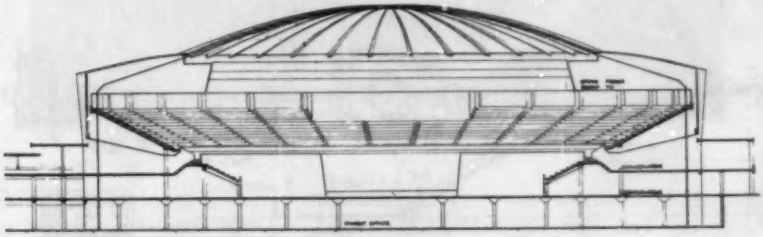


Fig. 11.—Memorial Auditorium, Dallas, U.S.A.

Fig. 12.—Model of Memorial Auditorium, Dallas, U.S.A.

for both the cantilever frames and the segments of the dome, resulting in great economy. The cost of the roof is considerably less than that of domes of similar size that have been built of structural steel or of concrete with complete falsework.

It is principally this repeated use of easily-moved falsework that permits the construction of large concrete buildings at comparatively low cost. One of the most outstanding examples is a new type of airplane hangar recently developed by the writer's firm. Hangars with cantilevered roofs and continuous doors are becoming increasingly popular with plane operators due to the freedom they allow in providing long unobstructed spaces. Although the use of concrete for cantilevered construction is not new, it has been apparent that the main obstacle to

using concrete for cantilevered roof construction is the weight, which normally increases rapidly with the span of the cantilever. For conventional cantilevered spans of 135 to 150 ft. the required average thickness of concrete in the roof, including the subframing and girders, might exceed 12 in. to 14 in. This would result in high cost of both the roof and the substructure. Such designs in concrete could not conceivably compete with light steel construction. Modifications are obviously necessary.

A concrete cantilevered hangar constructed in Rio de Janeiro in 1942 introduced several innovations to reduce the weight of the framing. An open truss was substituted for the usual solid girder, both to reduce the weight and make feasible

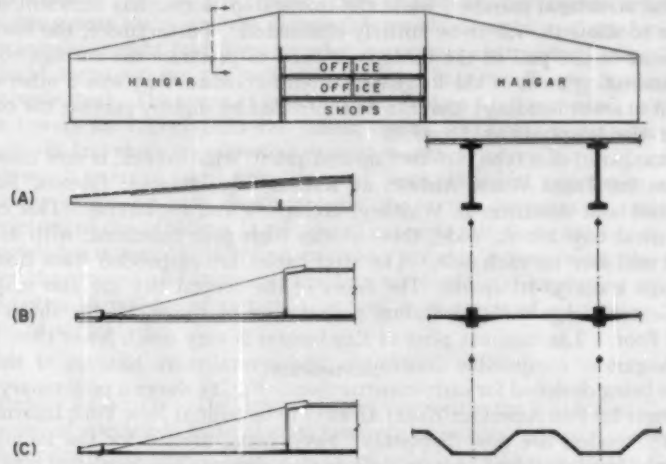


Fig. 13.—Cantilevered Frames.

a greater depth and better lever-arm. The roof deck was lightened by substituting a thin arched shell for the usual flat deck. In more recent attempts to find an economical solution, designs have been made for cantilevers with precast hollow or I-section girders combined with thin-ribbed precast deck slabs.

A study of the component parts of the structural system suggested another solution to the problem which has proved to be most satisfactory. The cantilevered ribs shown in *Fig.* 13a can be modified to retain only the effective working parts of the member ; these are the tensile steel and enough of the rib to resist the horizontal component of the tensile steel and to resist the shearing forces and bending moments caused by the roof load. If the roof slab is made an integral part of the rib, it will then assist in carrying the compressive forces caused by the cables. This system is illustrated by *Fig.* 13b. Although this system is considerably lighter than the original, the deck slab is still a fairly heavy member and the stiffening rib still requires as much or more concrete and steel as the deck. Further to reduce the weight of the deck slab and at the same time eliminate the stiffening ribs, the roof deck may be hipped as shown in *Fig.* 13c. The deck slab now has such a short span between folds that a 3-in. or 4-in. slab is completely adequate

Fig. 14.—Model of Hangar at Kansas City, U.S.A.

as a local structural member, while the corrugated section has sufficient over-all stiffness to allow the rib to be entirely eliminated. Furthermore, the horizontal component of the pull of the cable is utilized to prestress the corrugated shell, thus eliminating most of the longitudinal reinforcement that would otherwise be required to resist bending ; this can be controlled by slightly curving the corrugations in the longitudinal direction.

A hangar of this type, 816 ft. long and 420 ft. wide overall, is now under construction for Trans World Airlines at Kansas City, Missouri (Messrs. Burns & McDonnell and Ammann & Whitney, architects and engineers). This consists of a central bay 100 ft. wide, three stories high plus basement, with a 160-ft. cantilevered bay on each side. The steel cables are suspended from transverse anchorage walls 30 ft. apart. The floors of the central bay are also suspended from the anchorage walls, providing a clear span of 100 ft. for the shops on the ground floor. The contract price of this hangar is very much lower than that of steel hangars of comparable dimensions, and several more hangars of this type are now being designed for early construction. *Fig.* 15 shows a preliminary model of a hangar for Pan American World Airways to be built at New York International Airport ; tenders are now (September 1955) being invited for the foundations.

These few examples illustrate the fact that concrete has developed into a most reliable engineering material, and that construction equipment and methods have been developed to make it most economical, especially for very large projects where efficient site organization and repetitive operations are possible.

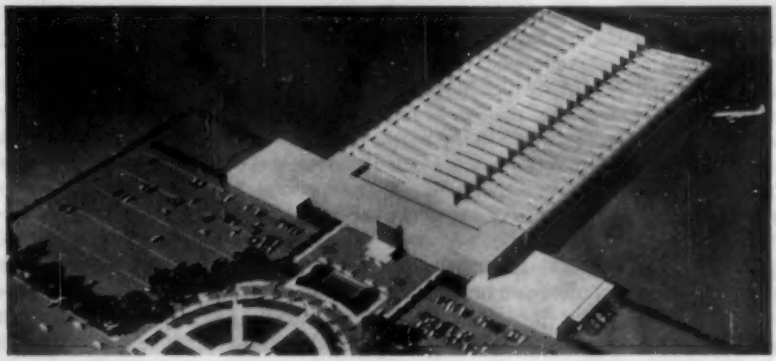


Fig. 15.—Model of Hangar at International Airport, New York, U.S.A.

GERMAN FEDERAL REPUBLIC

By HANS MINETTI

PRESIDENT, GERMAN CONCRETE ASSOCIATION.

THE introduction in France in the middle of last century of the combination of concrete and steel resulted in possibilities in new forms of construction unthought of by the inventors, and has since given rise to continual new theoretical and practical problems. In the past fifty years in Germany, for example, the permissible compressive stress in concrete has been raised from about 40 kg. per square centimetre (570 lb. per square inch) to 200 kg. per square centimetre (2850 lb. per square inch), and the permissible tensile stress in steel reinforcement has been increased eight-fold from 1200 kg. per square centimetre (17,000 lb. per square inch) to 10,000 kg. per square centimetre (142,000 lb. per square inch) in high-tensile steel. The spans of buildings and bridges have increased, reinforced concrete towers far higher than the tallest towers of Gothic architecture have been built—in fact there are countless examples of the Victory March of concrete. However much one can learn from the past, with its useful experience and its never-resting grappling with new problems, the writer proposes to present an overall picture of the problems in reinforced concrete still to be solved, or where more knowledge is needed. German engineers are now investigating the statics of frames, the stresses and strains of building materials, and improving efficiency through better knowledge of materials, as well as methods of calculating factors of safety of structures.

Research.

CODES OF PRACTICE.—The German Select Committee for Reinforced Concrete is composed of specialists in reinforced concrete, scientists, officials, contractors, and independent engineers. This committee, which is affiliated to the German Standards Committee, has the task of improving the design and construction of reinforced concrete structures by research and practical work, and the knowledge obtained is passed on to Government departments in the form of suggestions for improving regulations and recommended practices. Federal States issuing codes of practice all abide by these suggestions, so that there are uniform regulations throughout Federal Germany in spite of the great number of States empowered to issue codes. The committee receives considerable sums from the Government, the Federal States, and the concrete industry, but its revenue is still not sufficient.

PRESTRESSED CONCRETE.—In view of the growing importance of prestressed concrete, experiments are being made on the stresses in the compressive zone during the bending of members for short periods, with a view to ascertaining the stress distribution and the ultimate stresses in the concrete, and a report on the first part of these experiments, by Professor Rüsch of Munich, has been published. Further research is being made on T-section beams, on the influence of stirrups and longitudinal stiffeners, and on the effects of diagonal bending. Experiments have started at the technical universities of Stuttgart (under Professors Graf and Walz), of Hanover (under Professor Gaede), and of Munich to investigate the stresses and strains of prestressed concrete under static and dynamic loads.

For some years experiments have also been conducted on creep and shrinkage under varying external conditions and loads in order to check the validity of the existing regulations for the design of prestressed structures. Much attention is being given to reducing the losses due to friction during prestressing. Of particular interest is the method developed by Professor Fritz (Karlsruhe), in which longitudinal oscillations are produced in the spring-supported anchor-plate by blows from a heavy hammer, thus preventing friction by sudden jerks (*Fig.* 1). On further tensioning the cables and continuing the blows, the highest permissible tension can be applied in stages without losses due to friction, and overstressing at the anchorage is avoided (see "Deutscher Beton-Verein Vortrage", 1955, p. 347).

Further research is being made on the resistance to shearing of prestressed concrete, on the effect of the modulus of elasticity on deflection, and on the resistance to buckling of slender members especially under the influence of creep and eccentric loads to which the official safety factors do not apply. The strength

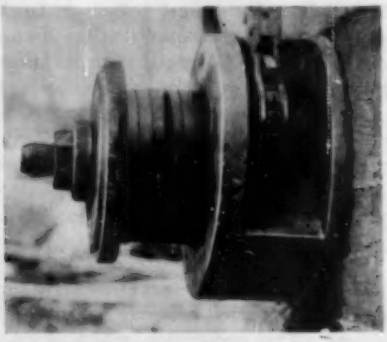


Fig. 1.—Method of Reducing Friction of Prestressing Wires.

and other properties of lightweight concrete, the effective width of the flange of T- and I-beams, bending moments on inclined slabs, the design of lattice beams with reference to the action of T-beams, and many other problems are being investigated.

CONCRETE.—Much research is being undertaken on improving the quality of concrete and steel. In Germany an impact test has achieved considerable popularity; this non-destructive test is made by measuring the area of the indentation made by an impinging ball. Investigations on the proportioning of concrete have been intensified, notably by Professor Hummel at Aachen; the best water-cement ratios for concrete with various admixtures have been ascertained; the effect of aerating and plasticising agents and the suitability of such agents for use in different conditions have been considered. Suitable mortars for grouting the joints between members, and which will not segregate and are frost-resisting, have been ascertained experimentally. The possible reduction in the cement-aggregate ratio has been investigated, with the accompanying reduction of heat generated in large masses of concrete, by including large stones up to 20 in., using the grouted concrete processes already developed in Great Britain

and the U.S.A., and by omitting aggregates passing a 0·1-mm. mesh. These methods have been used on large dams and found to be satisfactory. Experiments are in progress to determine the permissible cracking of concrete without corrosion of the reinforcement under various external conditions. The effects of moorland and sea-water and other waters detrimental to concrete are being investigated.

REINFORCEMENT.—A very important investigation includes the determination of the way in which the shape of reinforcement bars increases the bond between steel and concrete and thus influences the ultimate stress distribution in the tensile zone; this investigation includes ribbed and special steels such as flat bars with transverse ribs, flat strips, and pairs of cold-drawn wires welded to transverse bars. Widely distributed steel in the tensile zone of concrete reduces the spacing and the widths of the cracks. As a result of these tests it was possible

Fig. 2.—Store at Hanover.

to increase the permissible tensile stresses in plain or ribbed bars to 2800 kg. per square centimetre (40,000 lb. per square inch), and for the special steels to 4000 kg. per square centimetre (57,000 lb. per square inch) provided that the quality of the concrete, the size of the structural members, and the spacing of the reinforcement conform to the new regulations.

METHODS OF DESIGN.—At present there is in Germany still controversy on whether, with the increased permissible stresses in concrete, the present method of design should be used, or whether to employ the ultimate-load method already introduced in Austria and in Eastern Europe. The efforts of the French to arrive at a uniform method of design, at least for the western European countries, should have the support of all countries in view of their many common problems.

The foregoing gives briefly a general view of the way in which Germany is contributing to improving the design and construction of concrete structures, and these efforts will be intensified in future. This work, together with the ingenuity of engineers, with the contractors' willingness to adopt new ideas, and with the

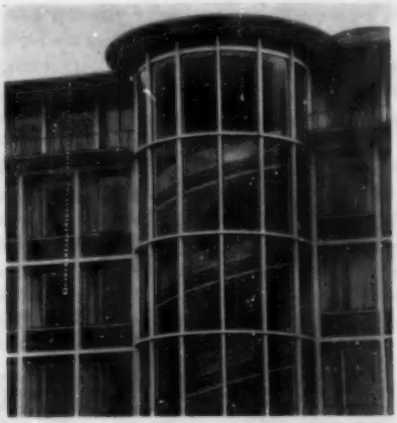


Fig. 3.—Building at Münster: Concrete Painted White.

intensity of competition within the industry and with other forms of building, has borne much fruit. Again and again concrete appears in new forms, and new applications have been made which a few years ago could be built only in other materials such as steel and timber. The accompanying illustrations of completed structures and the following short descriptions of their chief points of interest give some idea of what has been achieved.

Commercial and Public Buildings.

These buildings are almost entirely constructed with reinforced concrete frames because, due to the requirements of large window openings and few interior walls, brick buildings have not sufficient stability and steel structures are generally more expensive. In speed of erection there is hardly any difference between steel

Fig. 4.—Offices at Priessag, Hanover, with Untreated Concrete Surfaces.

and concrete; in the case of large reinforced concrete buildings one story can be added each week.

Even though it may be presumptuous for an engineer to write about architecture, it may be observed that in modern office buildings two styles of façades have appeared in great numbers. First, there is the use of glass on elevations in the form of broad bands of very large area and recessing of columns and beams of the supporting structure so that they are not seen on the elevation (*Fig.* 2). Secondly, the structure is emphasised by accentuating the dominant horizontal and vertical lines of the elevation and the concrete is not covered with another material. This style, known in America as "architectural concrete" because the concrete is not treated when the shutters are removed, or is coloured, or panelled by the use of liners in the shuttering or by chiselling, has become very popular in Germany (*Figs.* 3 and 4), as it is more economical and honest than faced or rendered concrete and allows, by the elimination of facing materials, more

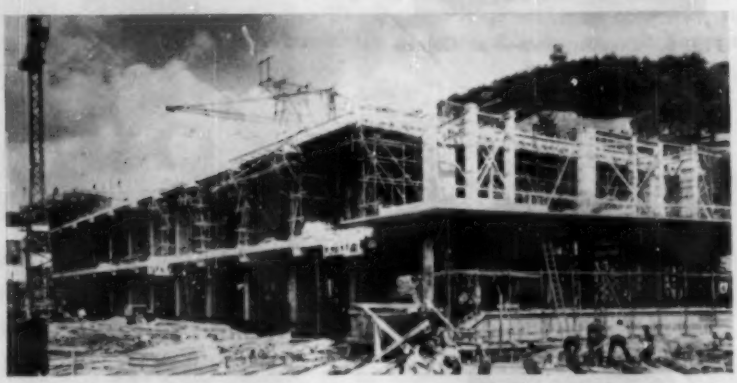


Fig. 5.—Building at Wurttemberg.

slender sections for columns and edge-beams, to which many architects attach much importance. It is possible to produce good "visible concrete" without faults only by careful work with skilled labour and much experience.

Industrial Structures.

Fig. 5 shows a textile factory in south Germany. Half the structure is founded on rock and the other half on sloping gravel. The unequal settlement was corrected by raising the columns, where necessary, in stages by means of built-in jacks. The cross beams of the superstructure are prestressed.

A reinforced concrete hyperbolic cooling tower is illustrated in *Fig.* 6. The diameter at the top is 23 m. (75 ft. 6 in.) and at the bottom 41 m. (134 ft.). The cooling capacity is about 10,000 cu. m. (2,200,000 gallons) per hour. The supporting columns are continued in the same plane as the wall, leaving large open spaces that increase the draught. Similar cooling towers have been built with precast units (*Fig.* 7); in this case in-situ concrete was used only at the

Fig. 6.—Cooling Tower at Gelsen Kirchen.

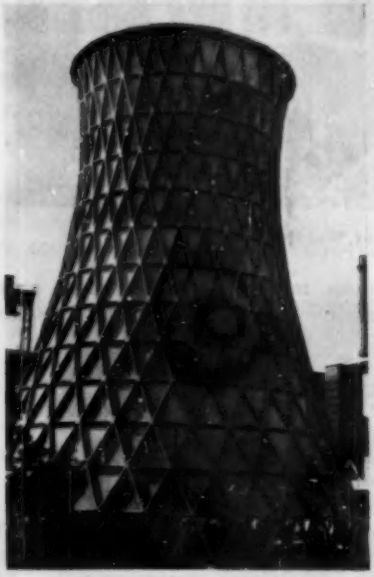


Fig. 7.—Cooling Tower at Berlin. Built of Precast Units.

Fig. 8.—Radio Tower at Wardböhmen: 230 ft. high.

intersections of the units, for the main tank, and for the sill-plate at the top ring-beam, and the construction time was only ten weeks including the cladding and the manufacture of the precast units.

Many towers have been constructed in reinforced concrete in the past few years for decimeter-wave radio-telephony, television, and radio transmission. These are of hollow cylindrical cross section and are constructed with sliding shutters (*Fig.* 8). The transmission and receiving plant at the top is on cantilevered platforms encased in glass. The sliding shutters used are of various systems, including one developed in Sweden using hydraulic jacks. A tower of this type (*Fig.* 9) is now being built near Stuttgart which has a total height of over 200 m. (680 ft.)—a concrete tower about 157 m. (515 ft.) high and a steel aerial 50 m. (165 ft.) high ; it is on the ridge of the range of hills surrounding Stuttgart, and dominates this lovely city. The tower has a slightly-curved conical shape, and was constructed with climbing shutters. Sliding shutters have also on occasion been used for blocks of flats (*Fig.* 10) ; this seems economical only in some circumstances, but due to the box-like construction, which is very stiff, such monolithic buildings have the advantage of great stability against horizontal

Fig. 9.—Radio Tower at Stuttgart : 680 ft. high.

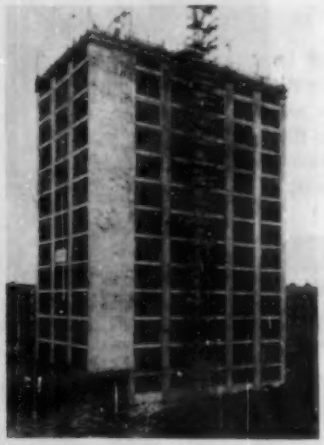


Fig. 10.—Residential Flats built with Sliding Shutters.

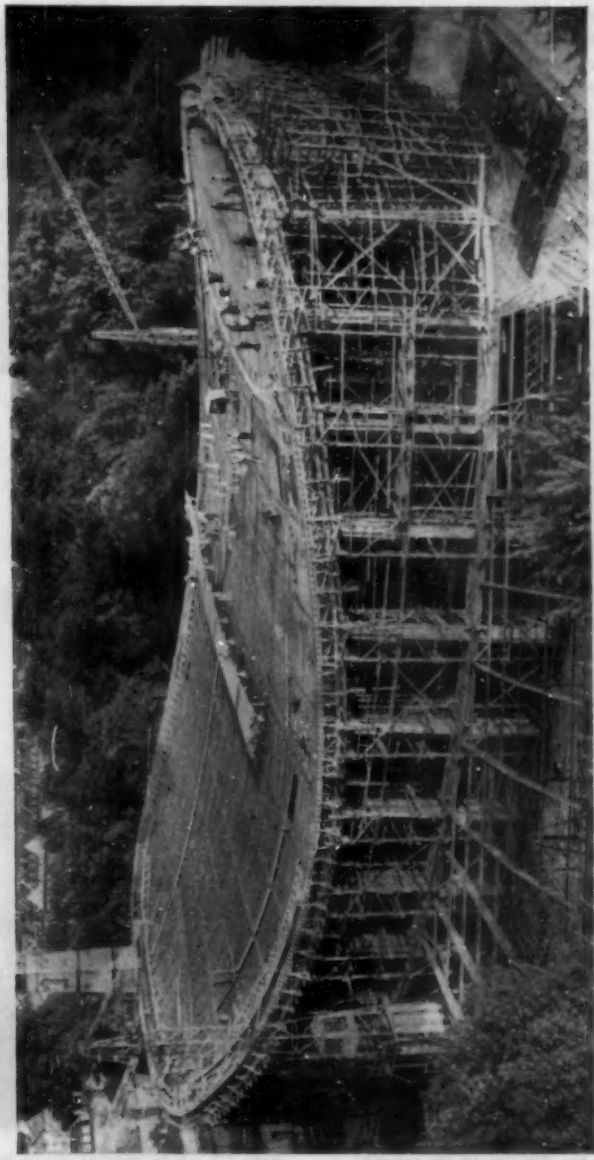


Fig. 11.—The Schwarzwald Hall, Karlsruhe, during Construction.

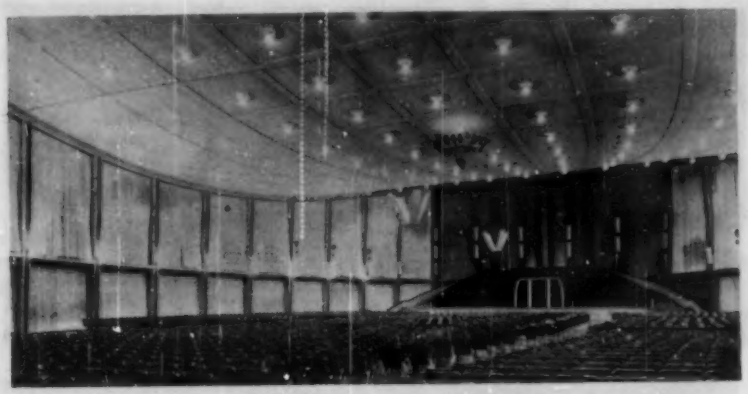


Fig. 12.—Interior of Schwarzwald Hall, Karlsruhe.

forces, an advantage of considerable importance in view of the desirability of obtaining as much resistance as possible to bomb-blast.

Figs. 11 and 12 show the Schwarzwald Hall in Karlsruhe, a suspended shell, prestressed by the Finsterwalder system, covering an area of about 46 m. by 75 m. (151 ft. by 246 ft.) and supported on an edge-beam with unsymmetrical curves and inclined columns; the strength of the shell lies in the system of ribs, which relieve the ceiling in a pleasing manner. Reinforced concrete shells have also been used for roofing railway platforms, for example at Koblenz (*Fig.* 13), and, more impressive, at Heidelberg (*Fig.* 14), where a new station for through trains has been built to replace the old terminus.

Prestressed Concrete.

Prestressed concrete is used for all types of structures, but special mention may be made of a method developed by Wayss & Freytag by which the frequency of vibration of foundations for machinery can be altered by the degree of prestressing of various components. In many structures the limited depth of construction and the small weight required can be provided only by prestressed concrete. Prestressing is also used, however, to increase the efficiency of structures

Fig. 13.—Platform Roof at Koblenz.

Fig. 14.—Concourse at Heidelberg Station.

by the absence of cracks and therefore increased life, and only seldom is it economy alone that results in prestressed concrete being preferred to reinforced concrete. There are in Germany, as elsewhere, many systems of prestressed concrete. With the exception of the Dyckerhoff & Widmann system, in which steel bars mostly of 26 mm. (1·02 in.) diameter with a breaking strength of 85 kg. per sq. mm. (121,000 lb. to 150,000 lb. per square inch) are used, and the Leonhardt system [using an end block around which pass stranded wires of about 2·5 mm. (0·10 in.) diameter and breaking strength of 170 kg. to 190 kg. per sq. mm. (243,000 lb. to 272,000 lb. per square inch)], steel of 5 mm. to 8 mm. (0·20 in. to 0·32 in.) diameter with breaking strength of 160,000 kg. to 180,000 kg. per sq. mm. (228,000 lb. to 257,000 lb. per square inch) is mostly used. These systems differ from each other in the main by their anchorages, anchor plates, and the number of wires per cable. This strong competition is mainly responsible for the incredibly fast development and the variety of prestressed concrete structures in Germany.

Precast Members.

The use of precast reinforced concrete structural members has not gained the same importance in Germany as in some other countries. Precast units are

Fig. 15.—Storage Sheds at Hamburg.

used in structures such as quay sheds (*Fig.* 15), the dome of Stephan's church, Karlsruhe (*Fig.* 16), for floors and roofs, and also as prestressed main beams for bridges of average spans. The deciding factors in the choice of precast units are cost and speed of erection, and last, but not least, the conservatism of men on building sites who will not readily accept new ideas.

Ready-mixed Concrete and Loose Cement.

Concrete batched at a central depot and delivered to building sites is widely used in the U.S.A., and certainly helps to prevent errors during mixing and, therefore, of variations of strength. At present there are two such works in Germany, and it is hoped that their experience will lead to an extension of this method of supplying concrete.

The delivery of loose cement has, on the other hand, made very rapid strides. Mainly on large building sites, but also on many smaller sites, are to be seen steel

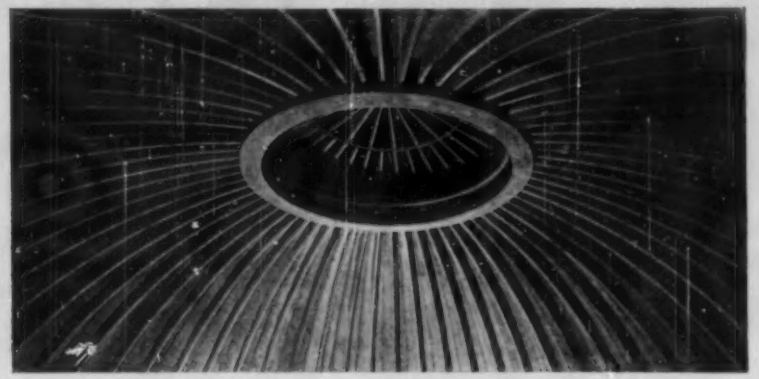


Fig. 16.—Dome of St. Stephan's Church, Karlsruhe. Built with Precast Segments 47 ft. long.

silos of capacities of 10 to 20 tons, complete with a weighing-scale and mostly with a screw-conveyor for discharge, into which cement is pumped pneumatically from the delivery lorries. There are also many possibilities in this method of supplying admixtures by weight to the mixers from smaller hoppers. Water-gauges increase the accuracy of the water-cement ratio, and this, together with the correct proportioning of graded aggregates, leads to greater accuracy in the manufacture of concrete on medium sized and small building sites as well as on larger sites with highly-mechanised concrete plant.

Civil Engineering.

There is a special pride in the heart of an engineer on the successful bridging of a deep gorge or wide river by means of a slender arch or beam spanning in an elegant line from pier to pier or from shore to shore. Here prestressing has been developed to a degree hardly envisaged a few years ago, and only girder bridges of small span are now constructed without prestressing.

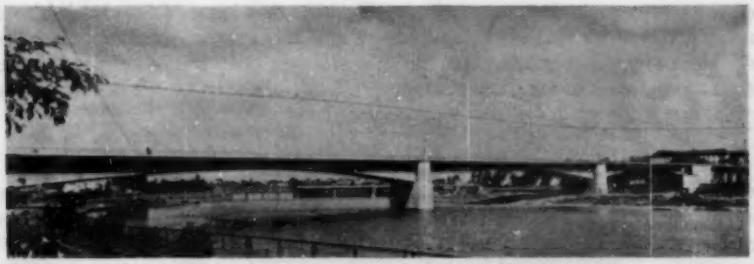


Fig. 17.—Prestressed Bridge at Koblenz.

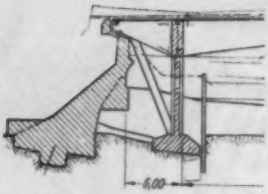


Fig. 18.—Abutment of Bridge at Ulm.

Fig. 19.—Consolidating Large Aggregate.

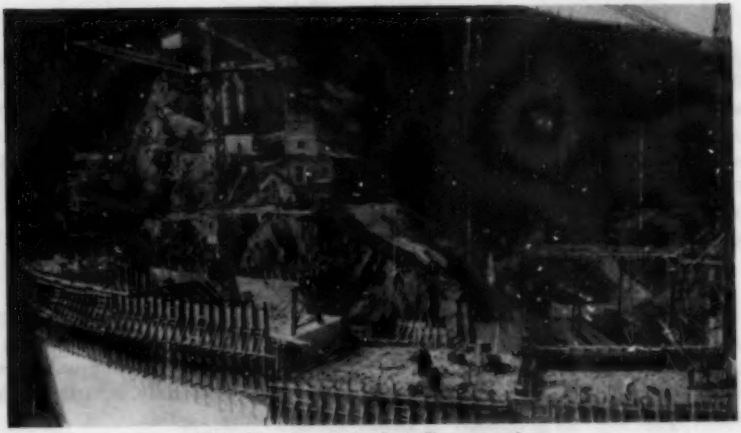


Fig. 20.—Dam during Construction.

Fig. 21.—Floating Landing Stage at Hamburg.

Fig. 17 shows a bridge with three spans between 102 m. and 123 m. (335 ft. and 403 ft.) over the Mosel, built on the system of Dyckerhoff & Widmann, A.G. This method has become well known as a result of previous works, particularly the bridge over the Rhine near Worms. The various sections are cantilevered out in lengths of 3 m. (10 ft.) and after the concrete has hardened each new section is anchored by prestressing steel to the completed portion of the bridge. This method of construction will certainly gain considerable importance in the building of large bridges.

The method shown in *Fig.* 18, a section of the end of a girder bridge consisting of a compressive member and a prestressed tensile member, is also used often. The magnitude of the prestressing force determines the magnitude of the bending moment in the arch and the forces at the ends are carried, without bending moments, to the foundations.

For dams, an arch type of construction is preferred, and slender proportions are generally used in order to reduce temperature stresses. Pieces of rock of up to 500 mm. (20 in.) and the concrete are placed separately in the shutters in roughly equal volumes and are consolidated by surface vibrators weighing about 2 tons and with a surface area of 2 sq. m. (21½ sq. ft.) or by powerful immersion vibrators. *Figs.* 19 and 20 show the excellent surface of the concrete, which has a cement content of 165 kg. per cubic metre (278 lb. per cubic yard), a

Fig. 22.—The Salzburgen–Munich Motor Road near Siegstorf.

compressive strength of up to 400 kg. per square centimetre (5700 lb. per square inch), and complete watertightness.

During both world wars, due to the scarcity of steel, concrete ships were built. In normal circumstances they would not be economical, but the experience gained from them led to the construction of large floating reinforced concrete pontoons with walls only 20 cm. (8 in.) thick; *Fig.* 21 shows a stage for submarines at Hamburg in which such pontoons were used.

Due to the great need for houses in the past ten years means are only now becoming slowly available for the resumption of road building (*Fig.* 22). The roads built in the 1930's have worn extremely well in spite of the unexpected increase in traffic during the past twenty years.

The German Concrete Association.

In conclusion, a few words about the aims and tasks of the German Concrete Association. It has been in existence for more than fifty years, and includes as members all firms concerned with concrete construction. As advising members, there are leading scientists, officials, and civil engineers, who have made particularly useful contributions towards the development of concrete. As their subscription the firms pay a percentage of the salaries and wages bills, which amount to more than 500,000,000 D.M. At the head of the Association is an executive committee of fifteen to twenty leading men of the industry who are elected yearly.

The tasks of the Association are manifold. They include collaboration in the experimental and research work of the German Select Committee for Reinforced Concrete, co-operation in preparing the regulations of the building authorities, the issue of technical publications, co-operation with other associations on related subjects and with the associations of other countries, and the collection, selection, and distribution of experience and knowledge by means of publications and lectures. At the annual general meeting new ideas and experiences are discussed, and more than 1000 engineers from Germany and other countries attend. The fifty volumes of the transactions of the Association are a comprehensive record of the development of concrete.

In order to advise members on their work experienced concrete engineers are employed to visit building sites and give advice, and also to point out bad practice and make suggestions for improvement. The members are bound to follow this advice and to follow implicitly the codes of practice; if members repeatedly offend against the regulations they must appear before an honorary court which can, to protect the industry, impose various penalties or even expel them from the Association. The experience of these advisers is carefully collected and, insofar as it is of general interest, brought to the notice of all members. In this way the Association serves its members and also benefits building owners and the whole national economy in developing concrete and perfecting it; the aim of the Association is " Highest Quality through Best Workmanship ".

YUGOSLAVIA

By BRANKO ŽEŽELJ

DIRECTOR OF THE INSTITUTE FOR TESTING MATERIALS, BELGRADE.

FIFTY years ago the peoples of Yugoslavia were still under foreign domination—all except the Serbians, in what was then called Serbia, who had earlier succeeded in liberating themselves after five hundred years of Turkish rule. The country was predominantly agricultural, lacking any engineering development, without any industry, with no good roads, and with few railways. Nevertheless, from about 1910 to the first world war there appeared the first important reinforced concrete road bridges in Slovenia (then under Austro-Hungarian rule). *Fig.* 1 shows a bridge of that period and which is still in use ; it is a reinforced concrete cantilevered bridge with a central suspended girder of 35 m. (115 ft.) span, over the river Ljubljančica in Ljubljana, and was built in 1912 to the design of Professor Kralj.

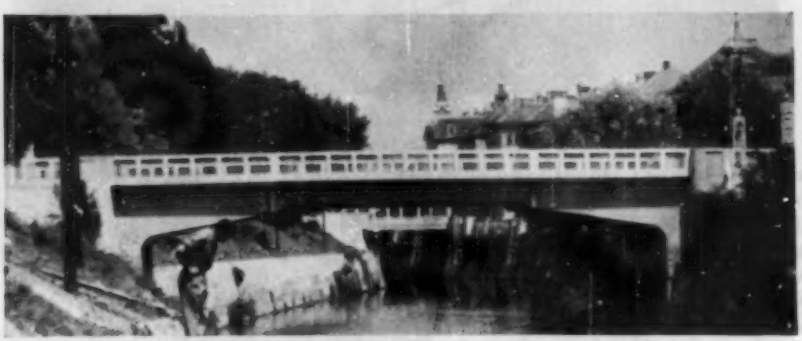


Fig. 1.—Bridge over the River Ljubljančica. Built in 1912.

The first world war stopped even these initial attempts, and when the war was over Yugoslavia, though united, was devastated and backward in technical development. The reconstruction, which lasted several years, was chiefly of communications, and included many railway and highway bridges which, however, were almost exclusively steel structures. Reinforced concrete gained ground but slowly. There were not many engineers, and hardly any experience in designing and building. Construction in reinforced concrete worth mentioning began only with the advent of the new generation of highly-qualified engineers about 1925.

First Development Period.

Between about 1930 and the second world war, reinforced concrete was used to an ever-increasing extent and gradually assumed the chief rôle in the development of the country. Many dwellings and public buildings were erected, as well as industrial projects and particularly road bridges. At that time reinforced concrete was already more economical than steel, and began to take its place in construction work. Most of the important reinforced concrete bridges, with

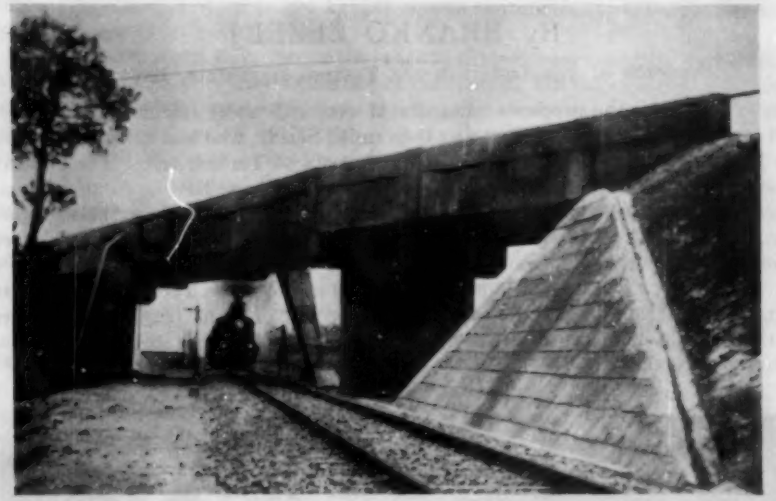


Fig. 2.—Road Bridge at Idjoš.

spans up to 60 m. (197 ft.) and of various types, carried roads. It is impossible here to give an adequate description of these bridges, but two examples are illustrated. *Fig.* 2, a bridge at Idjoš, designed by Professor Lazarević, has a skew of 18 deg. *Fig.* 3 is a bridge crossing the river Jerma and a bridge at a sharp angle. Skill in reinforced concrete rapidly improved and soon began to equal the engineering achievements of the rest of the world. This marked success was to a large extent due to the fact that Yugoslavia abandoned the contemporary German reinforced concrete standards in favour of the Swiss standards.

Perhaps the most important reinforced concrete structure of those days was the road bridge across the river Tara (*Figs.* 4 and 5), built between 1938 and 1940, to the design of Professor Trojanović. Situated on a plateau 700 m. (2300 ft.)

Fig. 3.—Road Bridge crossing Railway Bridge and the River Jerma.

Fig. 4.—Bridge over the River Tara.

Fig. 5.—Longitudinal and Transverse Sections of Bridge over the River Tara.

above sea-level, this structure, 400 m. (1315 ft.) long, spans the wild valley of the river Tara. The main span of 116 m. (380 ft.) is 150 m. (494 ft.) above the river-bed. The theoretical span of the arch is 116 m. (380 ft.) and the rise 23·71 m. (77 ft. 9 in.), giving a ratio of rise to span of 1 : 4·89. The main arch consists of two ribs joined by a slab which follows the line of the bending moment, so that the arch is H-shape. The remainder of the bridge consists of a viaduct of four spans of 47 m. (154 ft.) each. During the last war only the end span of the viaduct was demolished, and this was reconstructed immediately after the liberation. This is still the largest bridge and one of the most beautiful reinforced concrete structures in our country. Among framed structures of those days the thirteen-story " Albania " office building in Belgrade, designed by Professor Lazarević, deserves special mention.

But the short period of peaceful development and progress was soon over, and in 1939, when the menace of a new war was beginning to be felt, engineering development suffered as the country started to organise its defence. In 1941 the new war hit Yugoslavia very badly. Four years of ruthless occupation and

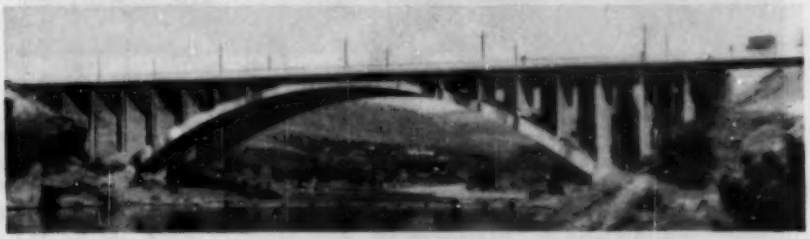


Fig. 6.—Bridge over the River Morača.

incessant fighting stopped all development, and the country was subjected to unprecedented devastation which spared hardly any engineering work.

After 1945 the whole country exerted its utmost powers to achieve reconstruction as quickly as possible, utilising such means and men as were available. It was a period of rebuilding all communications, such as railways, roads and harbours, including many large and small bridges ; they were days of makeshift and improvisation, of solving problems with whatever means were at hand. It was predominantly reconstruction in steel, often incorporating temporary solutions and making use of military structures, using reinforced concrete only sporadically.

Some Post-war Bridges.

In the first two or three years of reconstruction there were built several large and many small reinforced concrete bridges, the most important of which is probably the bridge (*Fig.* 6), designed by the writer, across the river Morača in Titograd. This bridge was constructed in 1947 to replace a steel bridge that was wrecked during the war. It is an arch bridge with a span of 80 m. (262 ft. 6 in.), a total length of 131 m. (430 ft.), and a width of 22 m. (72 ft.) including two footpaths each 4 m. (13 ft.) wide. The structure consists of two parallel, totally independent, arch ribs of box shape. The theoretical span of the arch is 79·4 m.

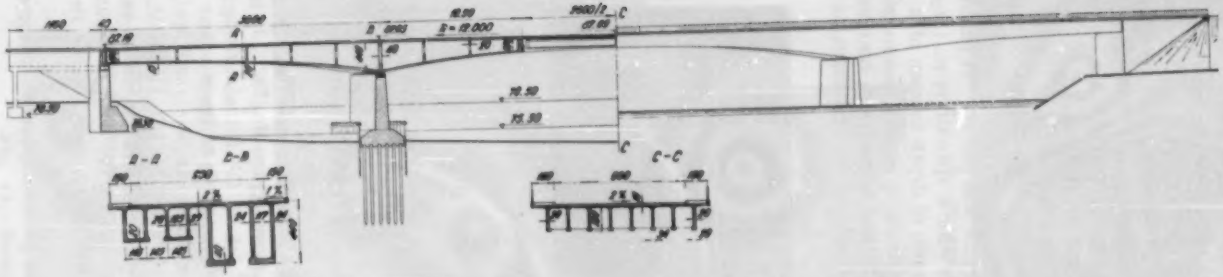


Fig. 7.—Bridge over the River Bosut : Longitudinal and Cross Sections.

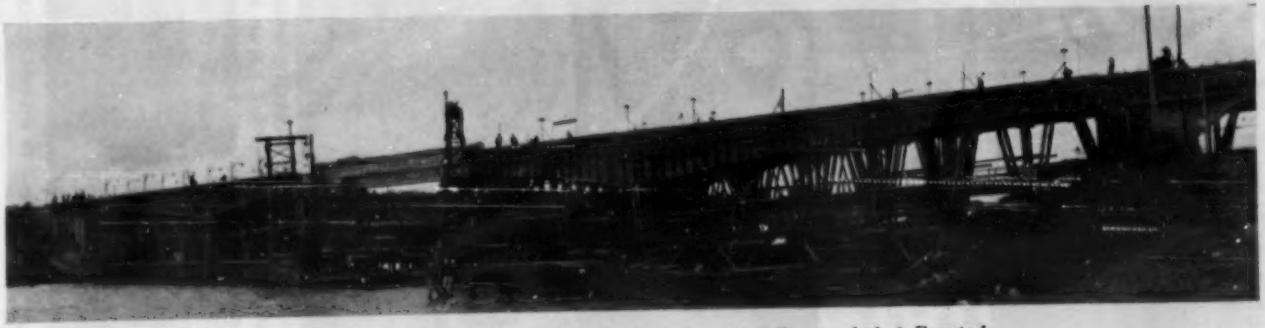


Fig. 8.—Bridge over the River Bosut : Suspended Beams being Erected.

BRANKO ŽEŽELJ (YUGOSLAVIA).

(260 ft. 6 in.) and the rise 13·82 m. (45 ft. 5 in.), which gives a rise-span ratio of 1 : 5·74. The floor consists of reinforced concrete slabs 6 m. (19 ft. 8 in.) square over the whole length of the bridge.

Towards the end of 1947 began the construction of the Belgrade–Zagreb motorway, with many bridges all in reinforced concrete. The most important bridge on this motorway, and the largest girder bridge in Yugoslavia, constructed towards the end of 1948, is the bridge (*Figs.* 7 and 8), designed by the writer, over the river Bosut. The middle span is 65 m. (213 ft.) long and the two end spans 38 m. (125 ft.). The width is 12 m. (39 ft. 4 in.), including two footpaths each 1·5 m. (4 ft. 11 in.) wide, and the total length 167 m. (548 ft.). This is a cantilevered bridge with a central suspended span that was precast. A feature of the bridge is the small depth of the central beam—for a span of 65 m. (213 ft.) its depth is only 1·8 m. (5 ft. 11 in.), that is, a ratio of depth to span of 1 : 36. The suspended central part was precast, and consists of eight I-beams 26 m. (85 ft. 5 in.) long and weighing 25 tons each. The end beams, with cantilevers, consist of four longitudinal box sections. In the middle of the end spans, in the

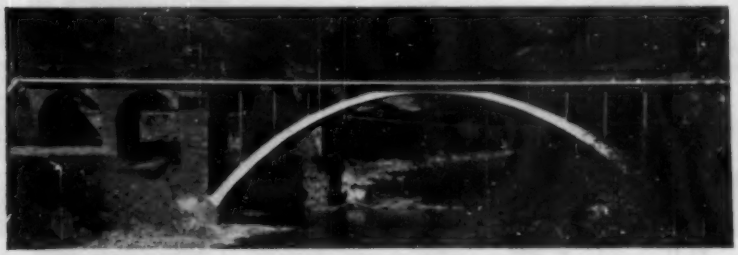


Fig. 9.—Bridge over the River Drina at Foča.

cantilevered parts, and in the middle of the suspended girder, a rigid transverse beam is provided.

During the past few years many reinforced concrete bridges of various sizes have been built and others are in course of construction on roads and railways. A few of these are shown in *Figs.* 9 to 13. *Fig.* 9 is a road bridge across the river Drina at Foča, and was designed by Mr. Marendić. The central arch has a span of 70 m. (229 ft.) and a rise of 19 m. (62 ft.) ; the width of the roadway is 7 m. (23 ft.) and the total length 120 m. (394 ft.). *Fig.* 10 is a road bridge across the Zapadna-Morava river, near Kraljevo, designed by Mr. Ilić. It has two arches of 62·8 m. (206 ft.) span and a rise of 8·5 m. (28 ft.), consisting of three-pinned arch ribs of hollow cross-section. The width of the roadway is 9 m. (29 ft. 6 in.). The angle of skew is 20 deg. *Fig.* 11 is a road bridge across the river Zrmanja at Obrovac, and was designed by Mr. Tonković, a lecturer at the University. It is built upon existing piers and abutments as a continuous beam with spans of 13·5 m., 42·5 m., and 13·5 m. (44 ft., 138 ft., and 44 ft.). The depth of the beam is 170 cm. (5 ft. 7 in.) throughout, and the rise-span ratio 1 : 25.

Fig. 12 is a road bridge over the river Neretva, in Jablanica, and was designed

Fig. 10.—Bridge over the River Morava at Kraljevo.

Fig. 11.—Bridge over the River Zrmanja at Obrovac.

Fig. 12.—Bridge over the River Neretva at Jablanica.

Fig. 13.—Bridge over the River Morava at Čačak.

by Mr. Kovač. The arch has a span of 48 m. (157 ft.), a rise of 37 m. (121 ft.), and the width of the road is 5 m. (16 ft. 5 in.); the total length is 110 m. (361 ft.). *Fig.* 13 is a road bridge across the river Morava at Čačak, and was designed by Mr. Erić, a university lecturer. It has five spans of 22 m., 29 m., 33 m., 29 m., and 22 m. (72 ft., 95 ft., 108 ft., 95 ft., and 72 ft.). The beams over the middle spans are continuous, while the end spans are hinged to allow for uneven settlement of the new and old piers and the abutments. The width of the road is 9 m. (29 ft. 6 in.).

Industrial and Other Buildings.

The application of reinforced concrete to structures other than bridges started only about the year 1930 and was stopped by the second world war.

Fig. 14.—Rolling Mill at Sisak.

It was not until 1947 that a great effort was made to develop the backward and war-devastated industries of the country, and during the past ten years reinforced concrete has taken first place among materials of construction for all kinds of structures, including many hydro-electric plants, steam power stations, metallurgical works, machine factories, industrial buildings for the electrical, cement, timber, textile, chemical, and other industries, shipyards, hangars, sports stadia, exhibition halls, silos, and reservoirs. It is here possible to give brief details of a few only of these structures.

The seamless-tube rolling mills at Sisak required the erection of 54,000 sq. m. (581,000 sq. ft.) of precast reinforced concrete construction. Three sheds, having spans of 28 m. (69 ft.) each and a total area of 16,000 sq. m. (172,000 sq. ft.), are in prestressed concrete (details of these structures were given by the writer in an article entitled "Le béton précontraint en Yougoslavie" in *Prestressing*, No. 1, 1952). Eight other sheds of the same span, with a total area of 38,000 sq. m.

(409,500 sq. ft.), have roofs of thin precast shells (*Fig.* 14) designed by Dr.-Eng. Werner. Braced arched roof trusses with ties, with spans of 28 m. (92 ft.) each, are spaced at 6·6 m. (21 ft. 8 in.) centres. Between the arches are prefabricated hollow-tile beams. Each arch rib consists of 27 elements which were assembled on the site with the aid of mobile scaffolding. The same type of roof was used in the construction of other factory buildings.

Various types of thin shell roofs have been employed. On the new railway station at Sarajevo, shells of a hyperbolic-paraboloid form were used, with a span of 31 m. (102 ft.) and a thickness of 5 cm. (2 in.). *Fig.* 15 shows cylindrical shells covering 30 m. by 9 m. (98 ft. by 30 ft.) with a thickness of 6 cm. (2⅜ in.) over the clinker store of the cement factory at Popovac, to the design of Mr. Krstić. *Fig.* 16 shows the exhibition hall at the Ljubljana Fair, designed by Mr. Smrekar, with a doubly-curved dome 40 m. (131 ft.) square and 8 cm. (3⅛ in.) thick supported at four points. Large areas of reinforced concrete, precast and cast in place, of many types, have been built, including the great Litostroj works in Slovenia, the Rade Končar works in Croatia, and the Viskoza works in Serbia.

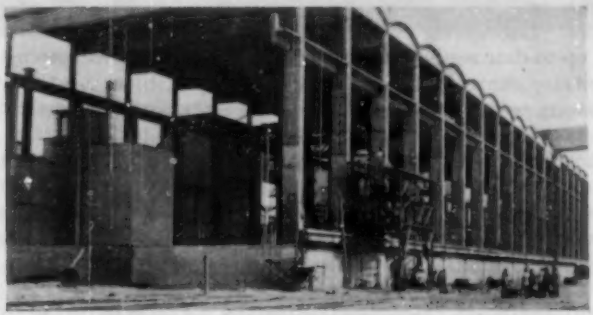


Fig. 15.—Clinker Store at Cement Works at Popovac.

Many hydro-electric plants have been built since the war. *Fig.* 17 shows the first large power station on the river Drina, near Zvornik. The height from the foundation to the crane girders is 42 m. (138 ft.). The installed output is 88 million watts. The designer was Mr. Stepanov, of the staff of the Energoprojekt designing office. Much work in reinforced concrete has also been done at several steam power stations; *Fig.* 18 shows part of the Vreoce power station, designed by Energoprojekt. *Fig.* 19 shows the new stadium for the sports club "Partizan" in Belgrade, designed by Professor Zadjina. The structure is partly of precast elements and partly concreted in situ.

During the past ten years reinforced concrete has been used to a very large extent, and one may safely say that all that was lost in regard to progress owing to the two great wars, which brought unprecedented destruction to Yugoslavia, has been made good in a short period of prolific technical and industrial development. Yugoslavia has a large cement industry producing good cement, and construction in reinforced concrete is therefore economically justified. To-day reinforced concrete in Yugoslavia has a tradition and considerable experience,

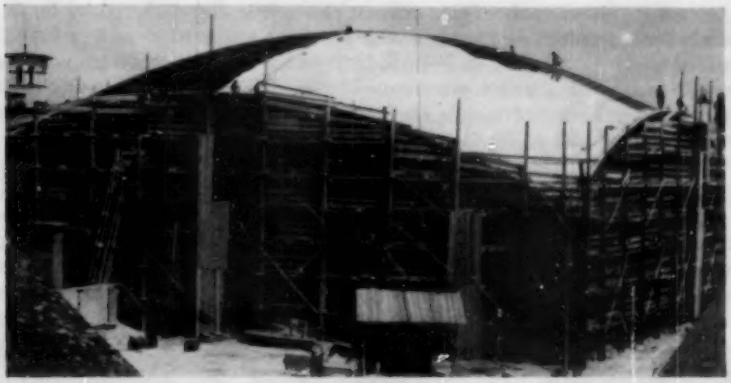


Fig. 16.—Roof of Exhibition Hall at Ljubljana.

and the country has produced designers and builders who can undertake the most difficult tasks. Engineering skill in Yugoslavia does not lag in the application of the most up-to-date methods of producing first-class concrete, precast elements, and prefabricated construction on a very large scale. Since 1950 the writer has been introducing prestressed concrete based on a new system of prestressing, and more than 100,000 sq. m. (1,000,000 sq. ft.) of factory buildings have now been constructed with prefabricated prestressed concrete, while many other buildings as well as bridges are in course of construction in prestressed concrete. The following is a brief review of some of the latest constructions in prestressed concrete which are interesting in regard to their conception and methods of construction.

Prestressed Concrete.

The prestressed concrete construction used for the cable factory at Svetozarevo (*Figs.* 20 to 22) is characterised by its novel design. Although completely pre-

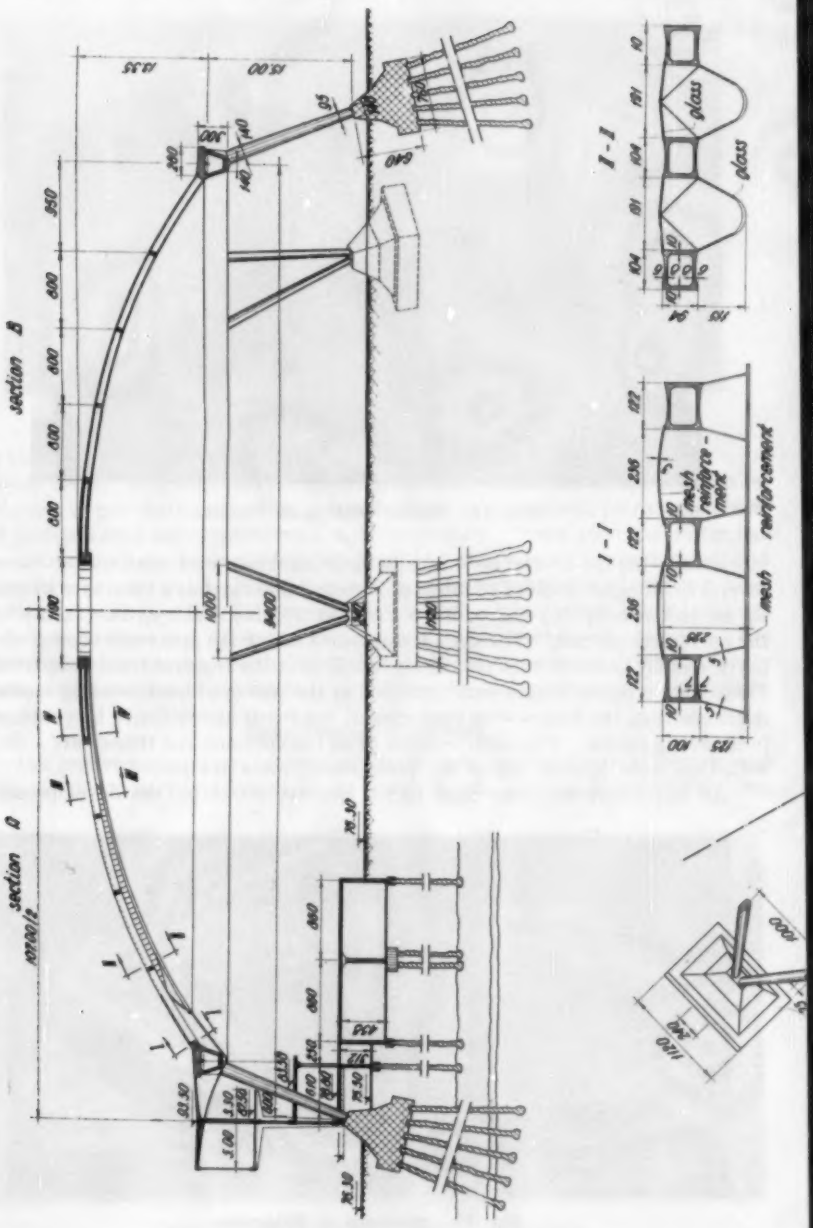
Fig. 17.—Hydro-electric Works at Zvornik.

Fig. 18.—Power Station at Vreoce.

fabricated, the structure is statically indeterminate and continuous through several buildings. A block of fourteen factory buildings has a total area of 26,000 sq. m. (280,000 sq. ft.) and widths of 26·6 m. (87 ft.) and 13·5 m. (44 ft.). All the parts were precast. The main frames are 8 m. (26 ft.) apart and consist of two parts, namely columns with cantilever brackets at the top and transverse trusses. Temporary erection hinges were provided in the region of least bending moment. After erection, the hinges were concreted at the joints and stiffened by continuous prestressing cables. The cross sections of all the columns and trusses are I-shape, with thin webs against which the prestressing wires are placed.

An important structure that had a decisive effect on the development of

Fig. 19.—Stadium at Belgrade.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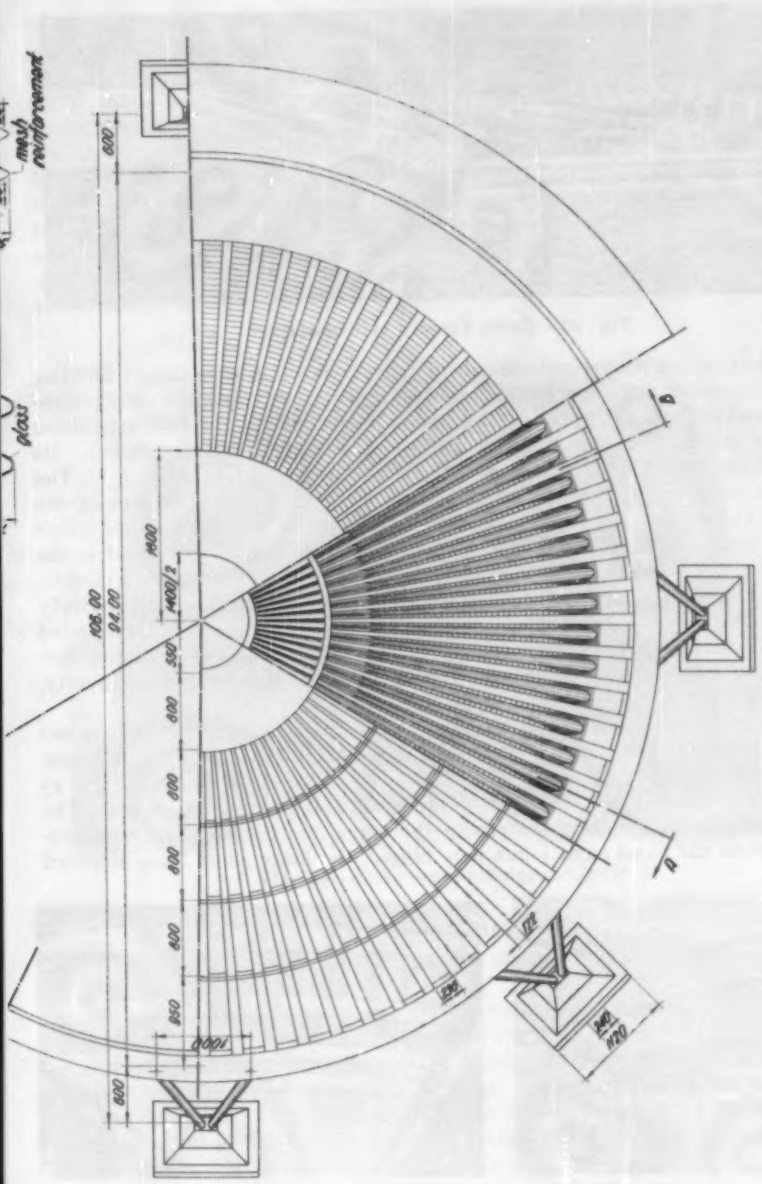

Fig. 28.—Details of Exhibition Hall for Belgrade Fair. *(See page 77.)*

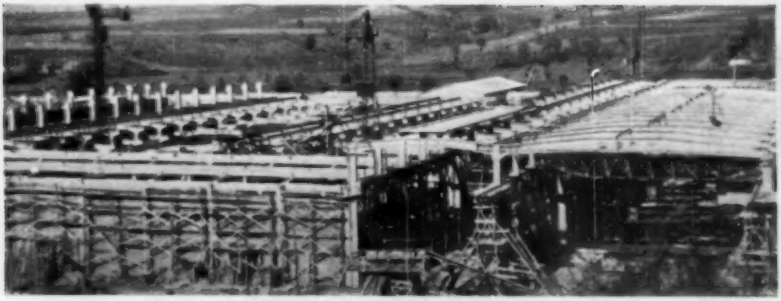

Fig. 20.—Cable Factory at Svetozarevo.

prefabrication and prestressed concrete in Yugoslavia was a large factory building at the shipyard at Split, which was (according to the writer's design) wholly prefabricated and incorporates various heavy and light members. This building adjoins six other similar reinforced concrete buildings constructed somewhat earlier. Its length is 160·8 m. (531 ft.), width 33·2 m. (119 ft.), and height 19 m. (62 ft.). The columns are 21 m. (69 ft.) apart longitudinally. There are crane-beams at two levels. The columns, of I-shape cross-section, are 21 m. (69 ft.) high and weigh 25 tons each. They were cast on the floor and erected in holes formed in the foundation. The crane-beams were particularly heavy precast elements. Ordinary beams, 21 m. (69 ft.) long, were first cast on the floor and partially prestressed. After the beams were lifted into position, their joints were concreted in situ on cantilevered brackets formed on the columns, and the remaining prestressing cables, which passed from one bay into the next, thus ensuring continuity, were then tensioned. The beams carry 40-tons cranes.

The roof trusses and their supporting girders were designed as prestressed lattice members. Before the work started, a truss and lattice girder were made and tested with loads up to the breaking load. Light lattice trusses (*Figs.* 23 to 25) with a span of 32·2 m. (105 ft. 6 in.) were placed 7 m. (23 ft.) apart. The joints between the members comprising the upper and lower chords were concreted, while the panel-point joints were hinged, the hinge effect being achieved

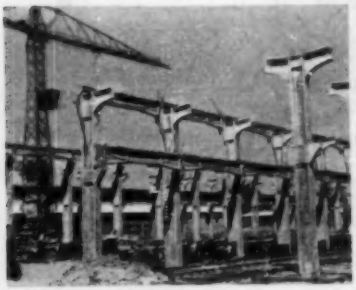

Fig. 21.—Columns at Cable Factory at Svetozarevo.

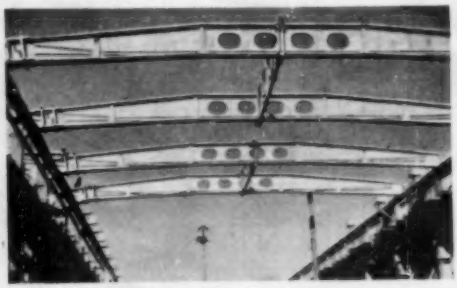

Fig. 22.—Beams at Cable Factory at Svetozarevo.

by means of lead bearing-plates. The panel-points of the upper chord afforded immediate supports for the purlins. The total weight of a lattice roof truss was only 10 tons. The precasting of the elements was done partly on the site and partly in a factory, while the assembling and prestressing were done in the building, several trusses being prestressed together in the longitudinal direction.

Beams of 21 m. (69 ft.) span, at a height of 19 m. (62 ft.), receive the loads from two roof trusses and also resist horizontal wind loads. These beams are also latticed and the middle panels are cross-braced by tensioned steel ties; the beams comprise a number of members and panel-point joints which were assembled and prestressed on the ground. Beams of the same design (*Fig.* 26), having a span of 25 m. (82 ft.), have also been used in the new shipyard building at Bijela, to the design of Mr. Stojadinović.

Fig. 23.—Structure at Shipyard, Split.

Current Construction.

It may be of interest to refer briefly to some of the structures now in course of construction in Yugoslavia.

A prestressed latticed roof construction having a clear span of 61 m. (200 ft.), designed by the writer's method, is shown in *Fig.* 27. The trusses are completely precast with panel-point joints, and are assembled on the ground beneath their position in the roof. The building is 60 m. (197 ft.) wide and 50 m. (164 ft.) long. The whole roof consists of only four trusses at 12·5 m. (41 ft.) centres. After assembling, each pair of trusses is connected by the roof covering, which is also placed while the trusses are on the ground. The pair of trusses thus tied together, complete with the roof covering, is lifted into position by hydraulic jacks between columns which serve as guides. The columns are assembled in

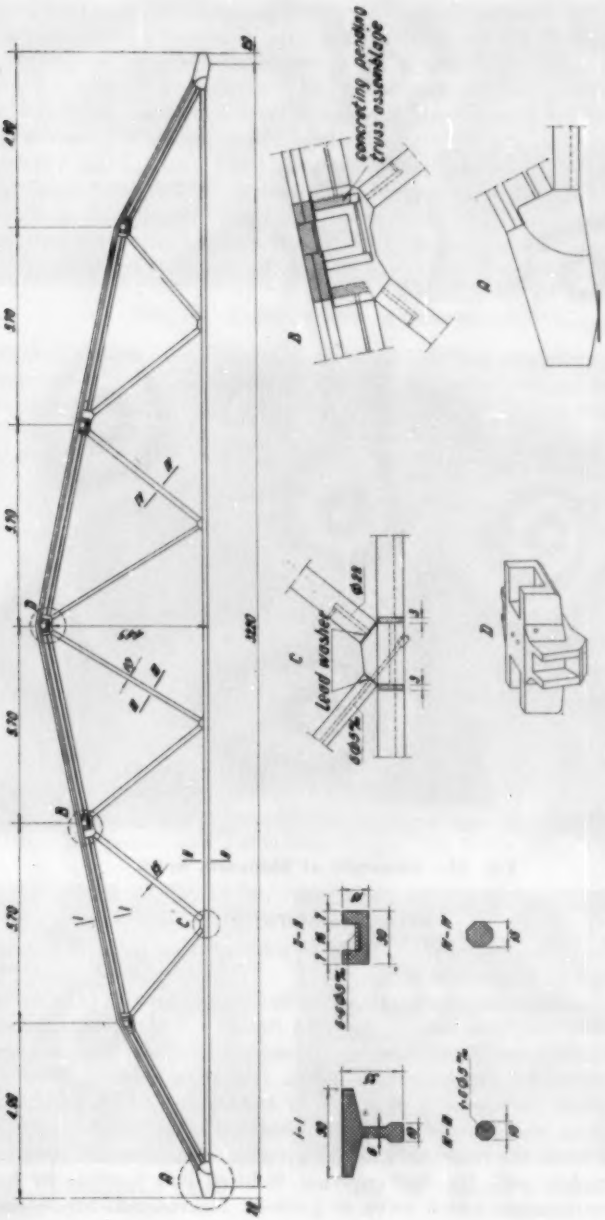

Fig. 24.—Details of Roof Trusses shown in Figs. 23 and 25.

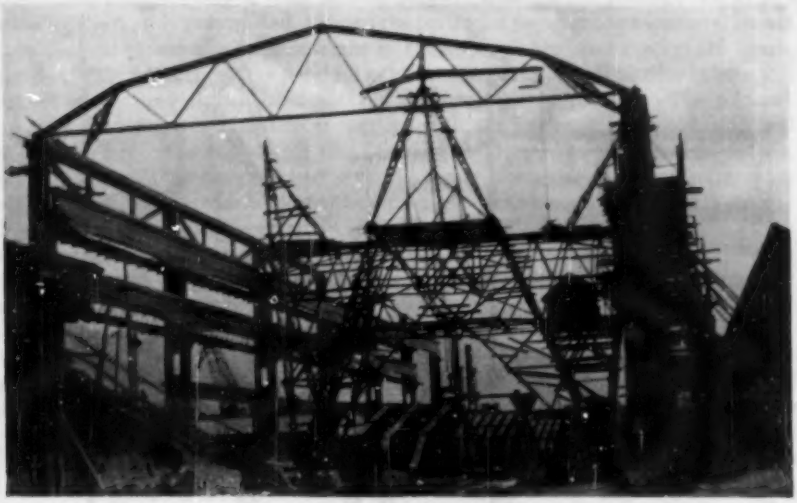

Fig. 25.—Building shown in Fig. 23 during Construction.

two stages : first only the flanges are erected, and as the lifting progresses the space between them is filled with concrete blocks to form the web, and the blocks are finally joined to the flanges by lateral prestressing.

Another, perhaps more interesting and much larger, structure, is the main exhibition hall (*Fig.* 28—see pp. 72–3) of the Belgrade Fair. It will be circular in plan, 107 m. (351 ft.) in diameter, covered by a dome supported on eight inclined double columns in the shape of a V. The dome will have eighty ribs of box cross section connected by six ring-beams. The uppermost ring-beam, which will be in compression, will form an opening of 11 m. (36 ft.) at the top of the dome. The lowest ring-beam, which will be in tension, will be a strong circular continuous

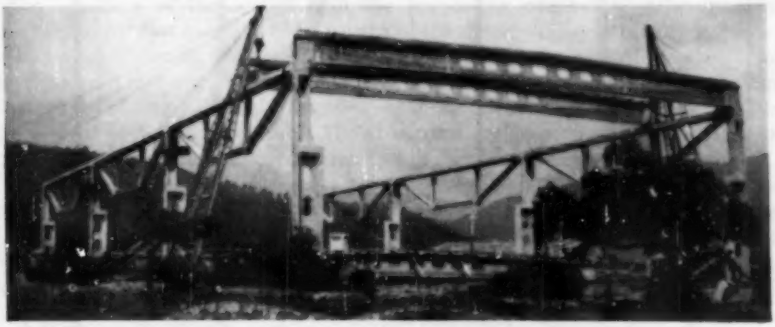

Fig. 26.—Structure at Shipyard at Bijela.

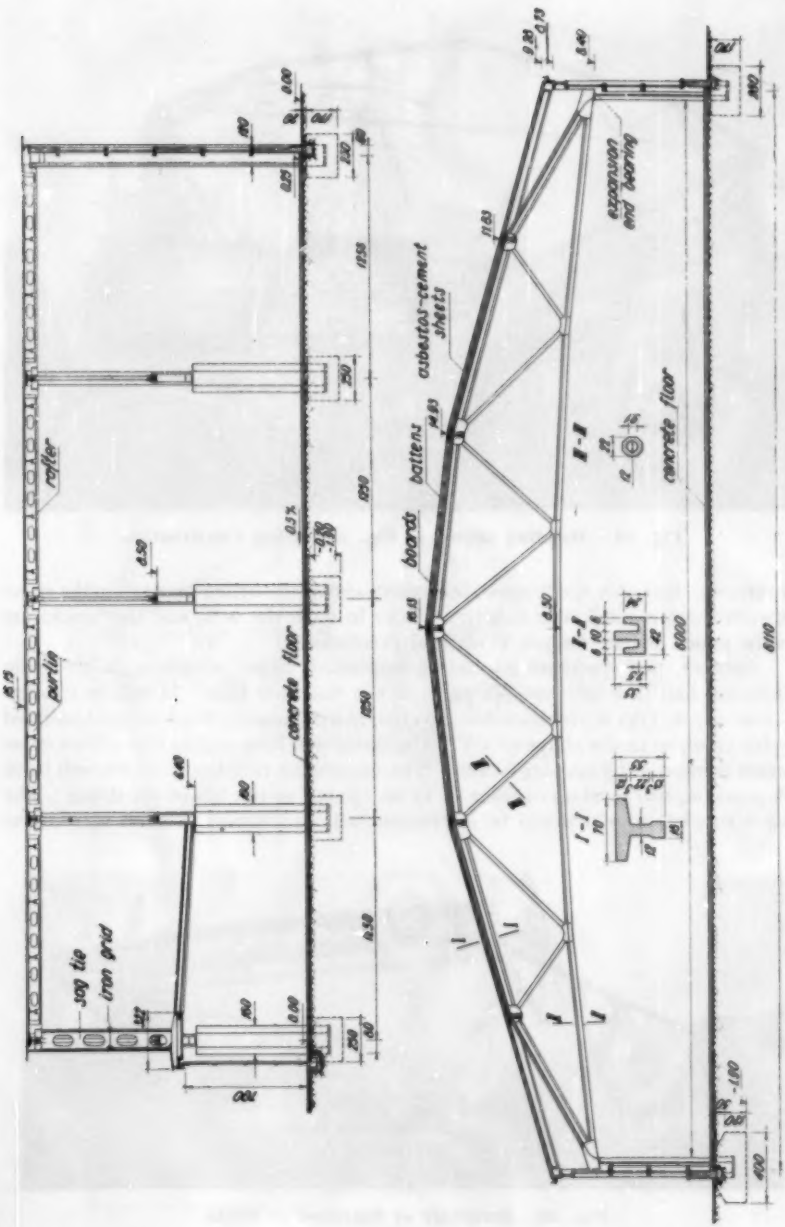

Fig. 27.—Lattice Roof Trusses of 200 ft. Span.

prestressed beam of hollow cross section supported at sixteen points. This ring-beam will be doubly prestressed, around the perimeter to resist the horizontal thrust from the dome, and also in each sector in the upper and lower flanges of the beam, to resist positive and negative bending moments on the beam. The ring-beams will be cast in situ, and all the other parts of the dome will be precast. The columns are conical with an elliptical cross-section, with pin joints at the bases, and will be concreted into the supporting ring-beam at the top. The ribs, or semi-arches, of the dome will be composed of several precast portions. The top part, 8 m. (26 ft.) long, will extend between the upper two ring-beams and be of I-shape; these will be precast and erected on scaffolding provided only in the middle of the hall over an area bounded by a circle of 27 m. (88 ft. 7 in.) diameter. When these eighty ribs are fixed in position, the upper slab will be cast in place, together with the top ring-beam which is 11 m. (36 ft.) diameter and with one-half of the 27-m. (88-ft. 7-in.) diameter ring-beam. The remainder of the semi-arch, 35 m. (115 ft.) long, will be precast in four parts. It will be of hollow cross-section and of conical shape, becoming smaller towards the top. The ribs will be assembled on the ground, immediately under their positions in the roof. The joints will be concreted and the arches prestressed by longitudinal cables. The erection of the precast ribs will be done by means of two cranes moving around the

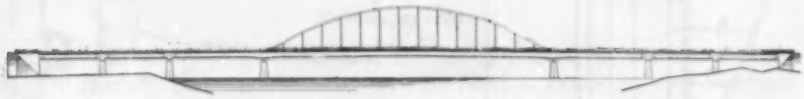

Fig. 29.—Bridge over the River Tisa, near Titel.

dome, one along the finished upper part of the dome, 27 m. (88 ft. 7 in.) diameter, supported by the scaffolding, and the other along the upper slab of the supporting ring-beam. The horizontal forces in the arches will be counteracted during erection by temporary ties. The arches have pin joints at the supports on the lower and upper rings, and when the erection of all the eighty ribs is completed, their connections with the 27-m. (88-ft. 7-in.) diameter ring-beam will be concreted before the intermediate ring-beams are concreted. By the use of hydraulic jacks at the junctions of the arches with the supporting ring-beam, a longitudinal thrust equal to that caused by the weight of the dome will be gradually imparted to the arches. Finally the rest of the intermediate ring-beams will be concreted. The dome will rest upon eight foundation blocks, supported on cast-in-situ piles. Other parts of the hall such as galleries, ground floor, and an annex, will be independent of the main dome. The structural design of the building has been prepared by the writer, and the architect is Mr. Pantović.

A third structure, now being erected to the design of the writer, is a new road bridge across the river Tisa, near Titel. The old structure, the steel construction of which was blown up during the war, consisted of two parallel lattice bridges, with spans of 120 m., 154 m., and 120 m. (394 ft., 538 ft., and 394 ft.). The piers and abutments were undamaged, and two separate bridges are being built on them, one for railway and one for road traffic. The new bridge (*Figs.* 29 and 30) retains the middle navigation span of 154 m. (538 ft.) while the end spans are

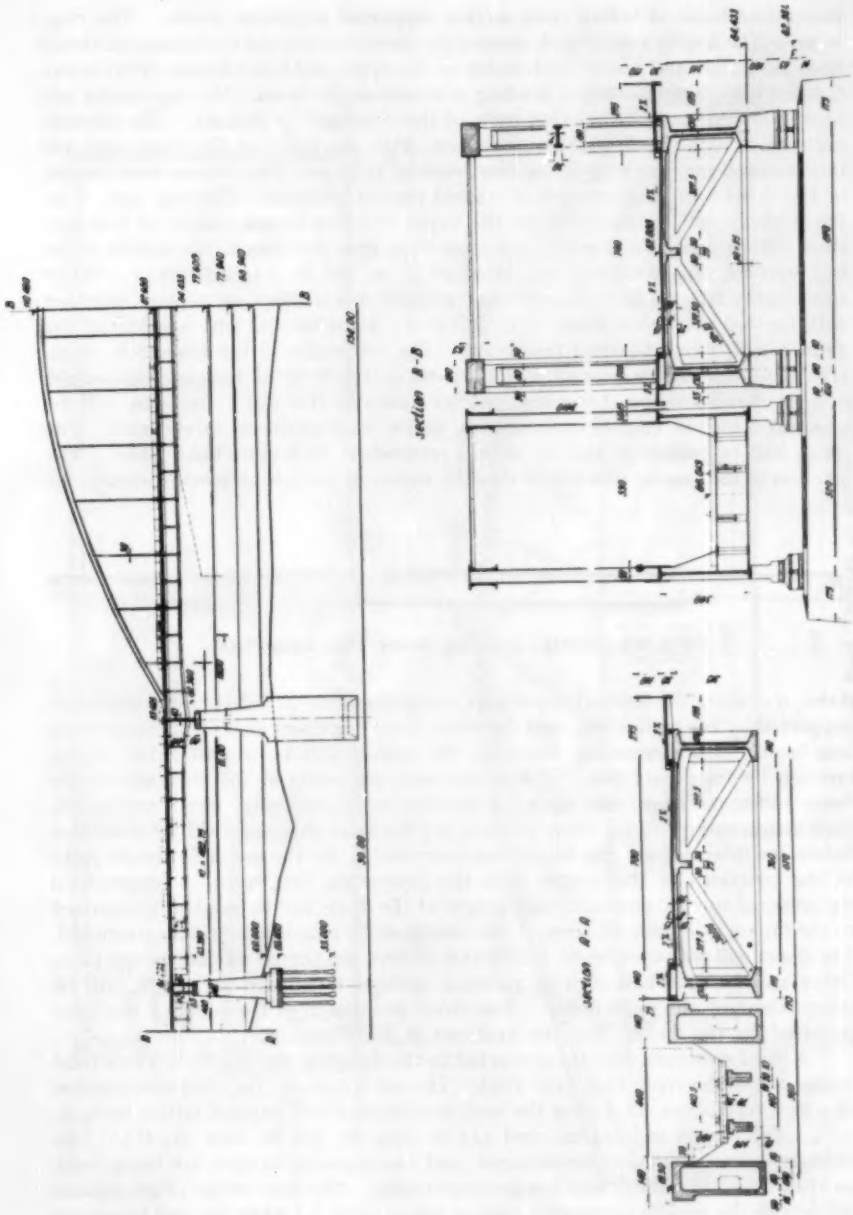

Fig. 30.—Details of Bridge over the River Tisa, near Titel.

being shortened by the erection of new piers. The middle opening is spanned by a bowstring arch, the bottom boom of which passes from the middle into the end openings, as a continuous boom, for a distance of 50 m. (164 ft.) each way. This middle portion, with spans of 50 m., 154 m., and 50 m. (164 ft., 538 ft., and 164 ft.), will be of steel for the railway bridge, while the remainder of the end spans and the whole of the road bridge will be of prestressed concrete. The lightness of this large structure is its chief characteristic. No concrete that was not essential has been included. The arch portion, having a rectangular cross section, will be stressed to its maximum of 164 kg. per sq. cm. (2275 lb. per square inch). The bottom boom members are I-shape with prestressing cables laid at the sides of the web. Corrosion will be prevented by guniting the cables. The vertical ties are also of I-shape in cross section and prestressed in the same way. Cross girders are light in weight, latticed, and deep, so that they rigidly tie together and stiffen the main girders. Secondary longitudinal beams divide the deck into small panels covered with thin slabs with transverse ribs. Before the arches are closed, secondary stresses in them and the greater part of the bending moment due to dead weight in the bottom boom will be counteracted by applying hydraulic jacks at the top of the arch to force the half-arches apart and lift the arch and the boom from the centering before the floor slab is concreted.

Retrospective.

The road to any progress has been difficult in Yugoslavia, and the development of reinforced concrete is no exception. Slavery, extending over hundreds of years, tended to keep the country at the lowest level of progress. Long wars of liberation, followed by the first and second world wars, impeded all progress, brought about a recession, and caused the destruction even of the little that had been achieved. Reinforced concrete has been able to develop during only twenty of the past fifty years—immediately before and after the second world war. In spite of such a difficult past, Yugoslavia to-day can be satisfied with its progress in reinforced concrete. The rapid post-war industrial development of the country has given a strong impetus to building construction, particularly in reinforced concrete. Experience is still being gained, design offices and contracting concerns are springing up, research laboratories and institutes are organised, old engineering schools have been expanded and new ones organised, and new generations of engineers are being trained and initiated into practical work. Before the last war Yugoslavia had a well-developed cement industry producing cements of high quality. The production has increased since the war, new factories are under construction, and the quality of cement is always improving. Most of the contracting concerns can now produce good concrete, and its quality is improving daily. It is not rare nowadays to use in some works concrete with a strength at the age of 28 days of 500 to 600 kg. per square centimetre (7000 to 8500 lb. per square inch).

A great deal of construction has been done and much valuable experience gained in the construction of nearly all kinds of reinforced concrete structures: many road and railway bridges have been built, also many dams, power houses, various industrial buildings, hangars, harbours, reservoirs, silos, power transmission lines, tunnels, difficult caisson foundation work, heavy machine foundations, and other structures where reinforced concrete can be successfully applied. It can

safely be said that reinforced concrete is the national building material in Yugoslavia, and that its use will greatly increase in future. Economic considerations demand the saving of steel and timber, and that is why ever new types of construction will be developed favouring prefabrication. In the past few years more than 100,000 sq. m. (1,000,000 sq. ft.) of prestressed prefabricated concrete structures of various types have been erected, valuable experience has been gained, and new and well-laid paths have been opened in the domain of reinforced concrete construction, without the use of timber shuttering and with the least use of steel.

Conclusion.

Although a material of outstanding potentialities, which has rapidly taken upon itself the main burden of construction in the world, concrete construction has by no means assumed its final form. The past fifty years have been a period of continual development and improvement in theory, practice, and investigation; it represents an unbroken progress of ideas, of forms, of improvement of the quality of materials, and of engineering methods; it has been a continual march onward of the spirit of engineering. Less than thirty years separate us from the time when the plastic properties of concrete were established, since when new possibilities have sprung up in the use of reinforced concrete for large spans and the foundations laid for the successful use of prestressed concrete. To-day, although much research work is being carried out all over the world, we are nowhere near the end of the investigation of these properties.

The theoretical bases of the design of reinforced concrete structures gradually cease to satisfy practice. The qualities of basic materials have improved to such an extent that theoretical assumptions regarding the composite action of concrete and steel are not in harmony with possibilities of making the best use of the materials. The theory of the limits of elastic deformation and design on the basis of the modular ratio persist through sheer inertia and their deep-rooted use in practice. The plastic theory, and design based on loads causing collapse, have not been adequately explained, nor do they provide a new conception.

High-quality steels are made in most countries, but their full use is not realised because of the inadequacy of theoretical assumptions in design, and also because the fundamental theory of the composite action of concrete and steel is no longer tenable. Stressing high-quality steel to its higher limits, the strain in the concrete cannot keep pace with the increased strain in the steel. There the advantages of reinforced concrete as a combination of two materials are ended. In a variety of structures, such as bridges, halls, reservoirs, power transmission lines, etc., reinforced concrete is giving way gradually to prestressed concrete, which is based upon new principles of the co-operation of concrete and steel and which offer infinite possibilities for their use to their best advantage.

Prestressed concrete has no similarity with reinforced concrete, in spite of the fact that the same two materials—concrete and steel—are used. We are abandoning the idea of reinforced concrete in favour of the concept of concrete used only in compression. We thus eliminate the greatest drawback of reinforced concrete, namely cracking. When the forces acting on concrete are limited to compression only, there can be no limit to the use of concrete of ever-increasing strength, the allowable stresses following closely on improvements in quality.

To-day new methods in reinforced concrete construction, and even more so in prestressed concrete, offer the greatest opportunities for further investigation, new conceptions, and new forms. It must, however, be admitted that it is not easy to walk along new and unbeaten paths; the realisation of every new conception is fraught with many uncertainties and even dangers. These, however, are the very conditions which appeal to men whose calling is engineering. He who decides to walk the beaten path will find himself only on the fringe of good craftsmanship, and it will not be long before he realises that he is falling behind and cannot overtake the general progress in reinforced and prestressed concrete.

To-day new conceptions in reinforced concrete, and to an even larger extent in prestressed concrete, have outstripped the bounds of the present standards for reinforced concrete, and one can safely say that the designer is free to create afresh. That, however, makes his work all the more difficult and laden with greater responsibilities, while his knowledge of the problems involved must be so much more profound. He must be acquainted in detail with the composition of materials, with construction methods and with the possibilities of achievement, and he must follow closely the process of the realisation of his conceptions. Our young colleagues who devote themselves to concrete have a wide vista of opportunities for work and engineering achievement, possibilities of developing new ideas, new forms, new constructions. Youth abounds with power, will, energy, and courage, all of which qualities a designer needs to-day more than ever before.

Finally, a word of warning. One cannot stress sufficiently the importance and need of cautiousness. New techniques in prefabrication, and particularly in prestressed concrete, offer the engineer wide, almost limitless, possibilities for creation. At the same time, however, they impose on him the need for the greatest possible care in all phases of design and construction. It is impossible to work to-day with precast and prestressed concrete without correlating design and construction to research work. There hardly exist two identical structures, while even the change of a building site may alter conditions of success into those of failure. It is therefore necessary in all our work, especially where new methods are tried, to carry out research work right through the designing and construction phases. Without a close co-ordination of these three sectors of achievement, it is not possible to build successfully in prestressed concrete. Wherever there is work in prestressed concrete, it must be carried out only upon such principles.

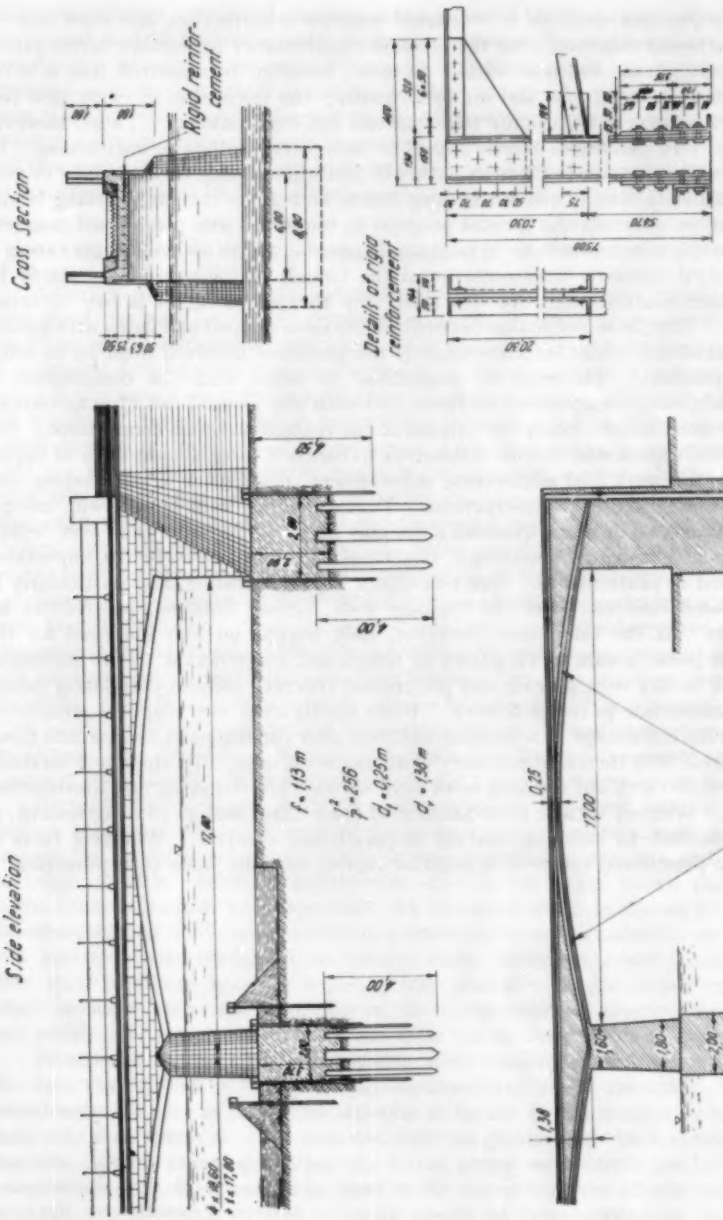

Fig. 1.—Road Bridge in Hungary. Built in 1892. (*See page 85.*)

HUNGARY

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SINCE in Hungary there has always been a scarcity of steel and timber, the development of reinforced concrete has played a very important role ever since its introduction. The earliest reinforced concrete structures in Hungary were some highway bridges designed and built by Robert Wünsch. His system (*Fig.* 1—see page 84) shows that he used a kind of "rigid reinforcement" that may be regarded as a predecessor of the Melan-Spangenberg method. A bridge over the river Nyitra at Érsekujvár, built by Wünsch in 1892 and still in use up to the second world war, comprised six spans of 17 m. (56 ft.) each. After the International Exhibition in Paris in 1900, Professor Sz. Zielinski gave a great impetus to reinforced concrete in Hungary. Among the structures designed by him at that period are several raft foundations, water towers, and a number of bridges. Before the year 1914 raft foundations were used to carry buildings of six and seven stories on the banks of the Danube in Budapest. One of several water towers designed by him between 1902 and 1912 is shown in *Fig.* 2.

Hungarian engineers and architects very soon became aware of the great advantages of reinforced concrete in all types of structures, and in the early years

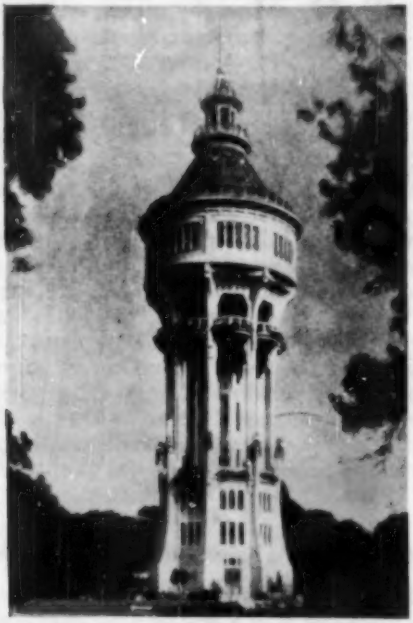


Fig. 2.—Water Tower on Margaret Island, Budapest. Built in 1906.

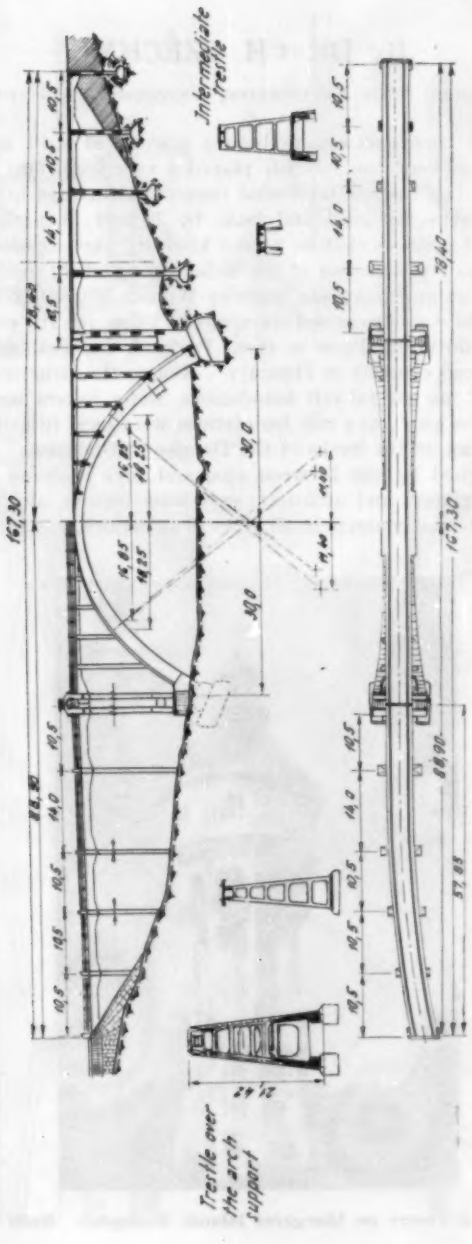


Fig. 3.—Railway Viaduct at Sinka. Built in 1907.

of this century reinforced concrete roofs, built on the Hennebique system, became very popular. In this development the engineers were supported by the contractors, who trained their staffs and acquired the rather simple equipment required for reinforced concrete work. The activities of Professor Zielinski and his collaborators were greatly facilitated by the report of a commission set up in 1903 by the Ministry of Commerce, which was very favourable to reinforced concrete, and which was elaborated and published as a book in 1905. The Association of Hungarian Engineers and Architects also set up a Commission, which in 1909 drafted the first specifications and regulations for design and construction in reinforced concrete.

Some remarkable reinforced concrete bridges were built before the first world war. Among these is the railway viaduct (*Fig.* 3) at Sinka, comprising a central arch of 60 m. (200 ft.) span, and approaches continuous over 47·15 m. (156 ft.) and 57·65 m. (190 ft.) at the ends. One of the approaches is curved in plan to carry the railway. This bridge was also designed by Professor Sz. Zielinski and partly modified by Professor J. Kossalka. The permissible stresses were as follows: Reinforcement in tension and in compression, 1200 kg. per square centimetre (17,000 lb. per square inch); reinforcement in shear, 960 kg. per sq. cm. (13,700 lb. per sq. in.); concrete in compression, 50 kg. per sq. cm. (712 lb. per sq. in.); concrete in tension, nil. The materials were specified to have the following strengths: Breaking strength of reinforcement in tension, 3600 kg. per sq. cm. (51,300 lb. per square inch); compressive strength of concrete cubes of 30 cm. (11·8 in.) sides at three months, 200 kg. per square cm. (2850 lb. per sq. in.). Tests showed that the required strength of the concrete could be obtained with a cement content of 376 kg. per cubic metre (631 lb. per cubic yard) provided that the proportion of water by weight did not exceed 48 per cent. of the weight of the cement; this is a proof that the importance of the water-cement ratio was well known and used in practice long before the tests made by Professor Duff Abrams in the U.S.A.

Another remarkable bridge, designed by Professor V. Mihailich, was built in Temesvár. The design was based upon the following permissible stresses: Compression in concrete, 35 kg. per sq. cm. (500 lb. per square inch); shearing in concrete, 4 kg. per sq. cm. (57 lb. per square inch); tension in steel, 1000 kg. per sq. cm. (14,200 lb. per square inch); shearing in steel, 800 kg. per sq. cm. (11,400 lb. per square inch). This bridge (*Fig.* 4) has cantilevered ends. Due to the limited height, a maximum depth of 1 m. (3 ft. 3 in.) only was available at the centre of the span and the banks of the river had a very small bearing capacity. The central span is 38·42 m. (127 ft.) long including side cantilevers each 11·36 m. (37 ft. 6 in.) long. In order to increase the lengths of the cantilevers, a counterweight of plain concrete was placed on the ends. The bridge is on a skew of 53 deg. and carries a roadway 10 m. (33 ft.) wide and two footpaths each 2·5 m. (8 ft. 3 in.) wide. It was built in 1908.

Structures Built Between 1918 and 1939.

A still greater development started after the first world war, when the scarcity of timber and steel was even more serious. Some secondary railway tracks were laid on reinforced concrete sleepers in 1925. After several improvements in their

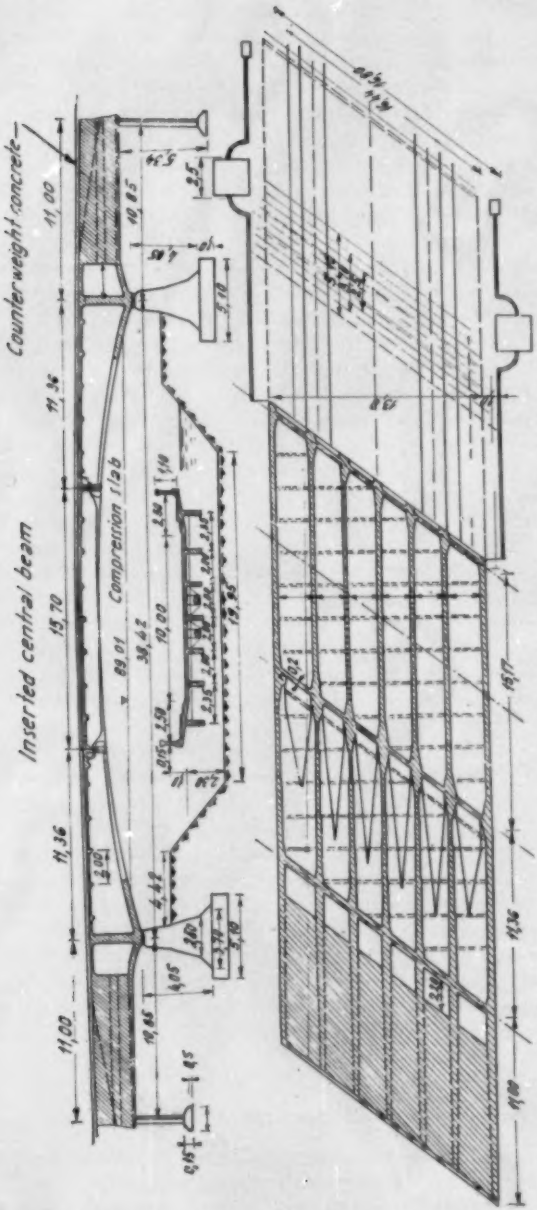


Fig. 4.—Bridge at Temesvár. Built in 1908.

shape and in the method of fastening the rails, the use of reinforced concrete sleepers has increased and they have proved satisfactory in service. The use of reinforced concrete roofs became general, and all larger buildings were built with reinforced concrete frames. All factories and warehouses were built of reinforced concrete, as well as all highway bridges with spans up to 40 m. (132 ft.).

Among the remarkable structures of this period are the grain silo (*Fig.* 5) in Budapest designed by Professor V. Mihailich, and factories and aircraft

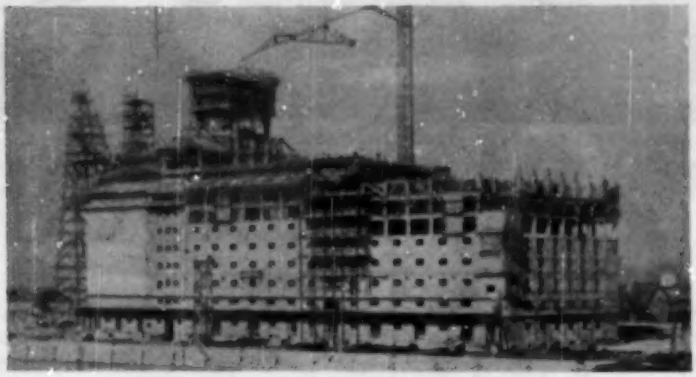


Fig. 5.—Grain Silo at Budapest. Built in 1925.

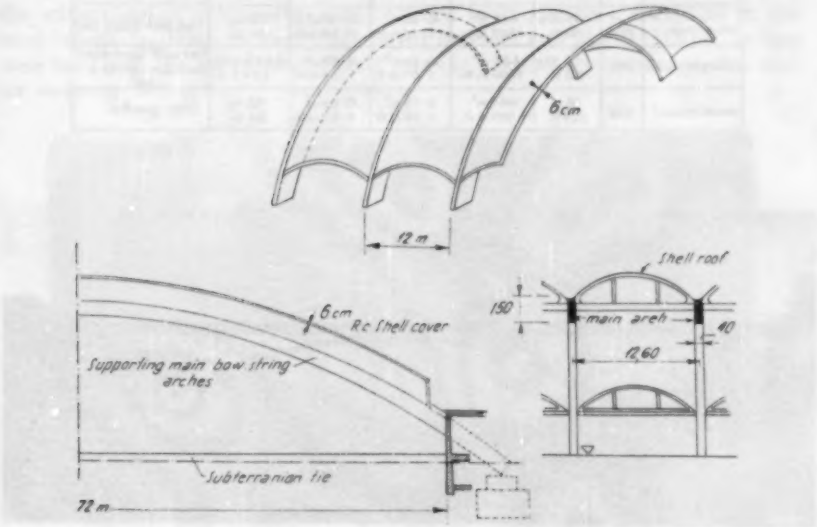


Fig. 6.—Shell Roof at a Garage.

Fig. 7.—A Bow-string Bridge.

TABLE I.—DECREASE IN QUANTITIES OF MATERIALS USED IN ARCH BRIDGES.

BRIDGE	BUILT	SPAN	SURFACE AREA	QUANTITIES per m² and per sq.ft.			
				TIMBER	CONCRETE	STEEL	
SZOLNOK	1938	44·2 m. 162 ft.	560 m². 6000 sq.ft.	0·60 m³ 1·97 cu.ft.	0·53 m³ 1·74 cu.ft.	99 kg. 20 lb.	arch rib with partially suspended deck
BERETTYÓUJFALU	1941	71·2 m. 235 ft.	910 m². 9800 sq.ft.	0·63 m³ 2·06 cu.ft.	0·53 m³ 1·74 cu.ft.	109 kg. 22 lb.	bowstring
RABAHIDVÉG	1949	61·2 m. 202 ft.	736 m². 8000 sq.ft.	0·16 m³ 0·53 cu.ft.	0·50 m³ 1·64 cu.ft.	235 kg. 48 lb.	bowstring with "rigid tubular reinforcement"
TISZAVASVÁR	1954	47·85 m. 158 ft.	422 m². 4600 sq.ft.	0 60 m³ 1·97 cu.ft.	0·50 m³ 1·64 cu.ft.	120 kg. 25 lb.	tied arch (cable tie)
IRRIGATION CANAL	1955	47·85 m. 158 ft	422 m². 4600 sq.ft.	0·60 m³ 1 97 cu.ft.	0·50 m³ 1·64 cu.ft.	108·3+11·5 kg 22+2 lb.	tied arch (prestressed deck slab used as a tie)
VARASD VIADUCT	1953	98 m 324 ft.	1440 m². 15,500 sq ft.	0·78 m³ 2·56 cu.ft.	0·66 m³ 2·62 cu.ft.	115 kg. 24 lb.	open spandrel

Fig. 8.—Bridge at Varasd. Span 325 ft.

hangars, also in Budapest, designed by Professor P. Csonka. A fresh impetus was given by the introduction of " shell " construction, which was used for the roofs of hangars and factories. A good example of this type of structure is the bus garage (*Fig.* 6) with a span of nearly 80 m. (264 ft.) designed by Dr. S. Menyhárd.

Bow-string bridges with spans up to 80 m. (264 ft.) have been built. One of these is shown in *Fig.* 7. The arches had a temporary hinge at the crown in order to counteract the effects of uneven settlement. A reinforced concrete bridge of 40 m. (132 ft.) span with a stiffening arch is an interesting example of early prestressing. In order to prevent cracks in the beams the deck of the bridge was loaded to produce tensile forces in the tie-rods before the beams were concreted. This type of bridge has undergone a further development in the past ten years by the use of high-tensile steel cables instead of tie-rods, and more recently a prestressed deck slab has fulfilled this duty. *Table* I shows the development of these structures and the gradual decrease in the quantities of materials required, including the largest spandrel-type bridge in Hungary, namely the bridge (*Fig.* 8) at Varasd built in 1953.

Recent Developments.

Reconstruction after the second world war was greatly assisted by prefabrication and prestressing, which further reduced the requirements of steel and timber. The need for economising in scarce materials and the urgency of the work resulted in the construction of a large number of composite bridges. In these structures, steel beams were welded together (mostly from material recovered from steel bridges destroyed during the war), and very little scaffolding was required. Also, the advantages of prestressing were obtained by producing a curvature in the steel beams, as shown in *Fig.* 9, before the concrete was placed. Other bridges were built with the use of welded steel tubes to serve as reinforcement, also with an economy in staging.

Fig. 9.—A Composite Prestressed Concrete and Steel Bridge.

Fig. 10.—Bridge over a Railway.

Improvements in design and of the quality of concrete made it possible for the quantities of material to be reduced. For example, in beam-and-slab bridges the number of beams and the thickness of the deck slab were considerably reduced. The most advantageous cross-sectional arrangement is when only two main beams carry cross beams spaced at wide intervals and the deck-slab spans in two directions. Recently a design (*Fig.* 10) has been introduced by Mr. E. Bölcskey which is advantageously used in spanning railways in cuttings. The supports are V-shaped and permit a more favourable distribution of bending moment on the beam and also reduce the bending moment. The development of beam bridges is shown in *Table* II.

PREFABRICATION.—In the prefabrication of buildings the precast elements are generally placed in position by mobile cranes or travelling stages by the system devised by Mr. A. Major and shown in *Fig.* 11. The frames are cast in a vertical position side by side, and then lifted and moved by travelling stages to the

TABLE II.—DECREASE IN QUANTITIES OF MATERIALS USED IN BEAM-AND-SLAB BRIDGES.

BRIDGE	BUILT	SPAN	SURFACE AREA	SLENDERNESS RATIO	QUANTITIES per m² and per sq. ft. CONCRETE	QUANTITIES per m² and per sq. ft. STEEL	
TEMESVÁR	1908	10·85 + 38·42 + 10·85 m. 36 + 126 + 36 ft.	401·8 m² 4700 sq. ft.	$\frac{1}{38}$	0·70 m³ 2·30 cu. ft.	83 kg. 17 lb.	7 main beams
BALSA (APPROACH SPANS)	1928	15·3 + 18 + 15·3 m 50 + 59 + 50 ft	281·6 m² 3140 sq. ft.		0·62 m³ 2·03 cu. ft.	83 kg. 17 lb.	4 main beams
GÉGÉNY	1942	17 + 19 + 17 m 56 + 62 + 56 ft	424 m² 4550 sq. ft.		0·50 m³ 1·64 cu. ft.	61 kg. 13 lb.	4 main beams
SIÓ (SZEKSZÁRD)	1952	20·5 + 38 + 20·5 m 67 + 125 + 67 ft	750 m² 8100 sq. ft.	$\frac{1}{21·5}$	0·72 m³ 2·36 cu. ft.	97 kg. 20 lb.	3 main beams
HERNÁD (GESZTELY)	1952	24·6 + 36 + 24·6 m 81 + 118 + 81 ft	688 m² 7400 sq. ft.	$\frac{1}{18}$	0·42 m³ 1·38 cu. ft.	75 kg. 15 lb.	2 main beams
POLGÁRDI	1953	8·7 + 22·6 + 8·7 m. 28 + 74 + 28 ft	380 m² 4100 sq. ft.	$\frac{1}{17}$	0·43 m³ 1·41 cu. ft.	87 kg. 18 lb.	2 main beams
RABA (RÁBA)	1947	18 + 22 + 18 m. 59 + 72 + 59 ft.	464 m² 5000 sq. ft.		0·16 m³ 0·53 cu. ft.	116 kg. 24 lb.	composite girder continuous over 3 spans

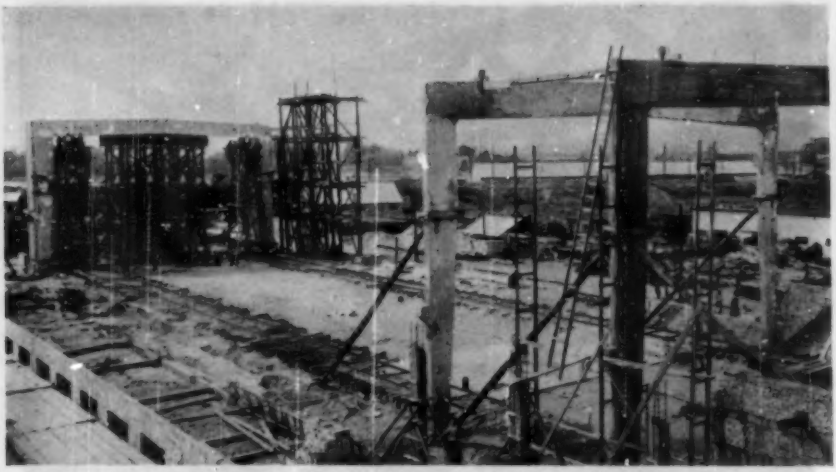


Fig. 11.—Precast Frames Cast Vertically.

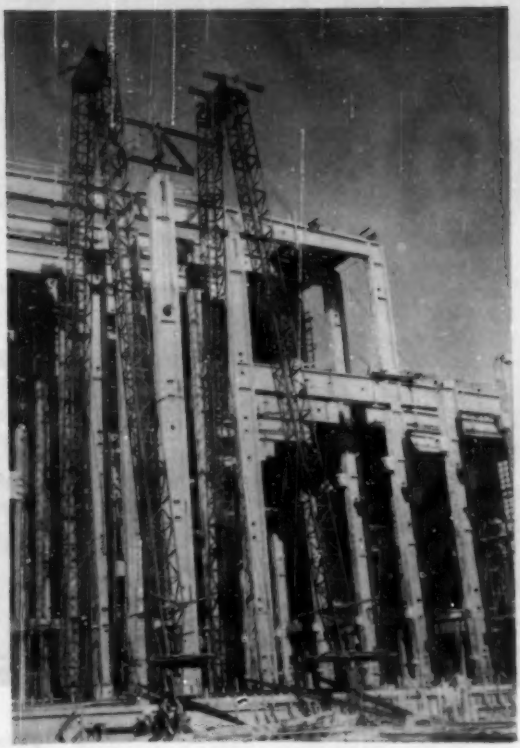


Fig. 12.—Columns and Beams Weighing up to 58 tons Cast Horizontally.

Fig. 13.—Precast Lattice Beams.

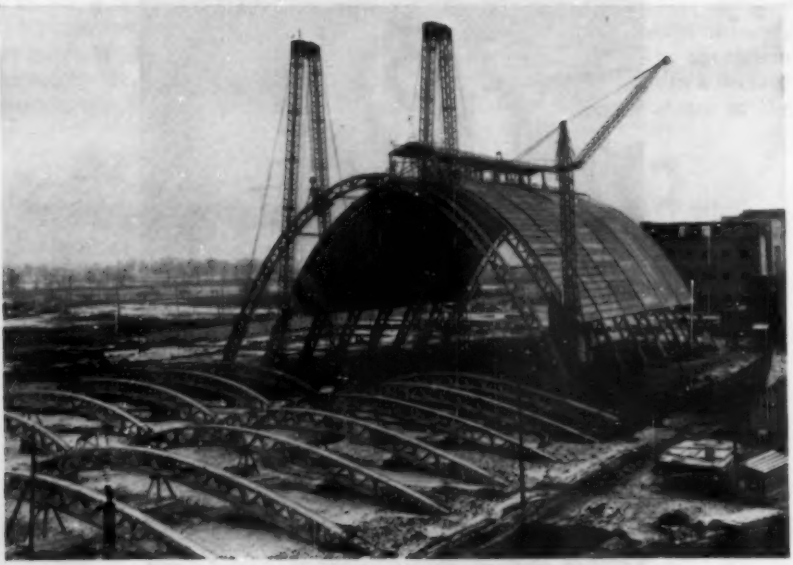


Fig. 14.—Precast Elements for a Salt Store.

previously-prepared foundations.* Another system (*Fig.* 12) comprises columns and beams cast horizontally on the site. The shutters are also of concrete, coated on the inner faces with a layer of plaster. These members are lifted and placed in position by pairs of travelling shear-legs. Members weighing up to 58 tons have been made and erected by this method, and the junction between them is made by welding together the protruding reinforcement bars. This system was developed by Mr. I. Mátrai Grünwald, and has been successfully used for several structures. Smaller structures are built with lighter precast elements, including lattice beams (*Fig.* 13), erected by cranes.

Another example of prefabrication is the large salt store shown in *Fig.* 14. The three-hinged arches have a span of 46·15 m. (152 ft.). They were cast in halves on the site, turned through 90 deg., and one end placed on the previously-prepared foundations. They were then lifted as shown and the halves kept in position until the hinges were cast at the crown. The roof slabs were also precast on the site. This system was designed by Mr. N. Gnädig.

Fig. 15.—Bridge with Precast Beams 83 ft. Long.

An interesting precast bridge is the three-span viaduct shown in *Fig.* 15. The main beams are 25 m. (83 ft.) long, 0·4 m. (1 ft. 4 in.) wide, and 2·5 m. (8 ft. 3 in.) deep, and were precast and lifted on to the piers; the engineer is Mr. Bölcskey.

The most imposing structure composed of precast elements is, however, the new stadium at Budapest (*Fig.* 16). It measures 275 m. (910 ft.) by 335 m. (1100 ft.), and can accommodate more than 140,000 people. The total length of prefabricated elements exceeds 45 km. (28 miles). *Fig.* 17 is an external view. The architect is Mr. Ch. David and the engineer Mr. E. Gillyén.

PRESTRESSED CONCRETE.—So far not a great deal of prestressed concrete has been used in Hungary, but some original prestressing methods have been invented and used. The first application was the construction of some small bridges, with spans up to 16 m. (53 ft.), by the pre-tensioned wire process (*Fig.* 18). Later bridges were built on the prestressing systems devised by Mr. B. Gnädig and Mr. E. Thoma and Mr. E. Böröcz. The Gnädig-Thoma system (*Fig.* 19) is a post-tensioned steel process in which the cables are anchored at the end cross beams and pass freely between the longitudinal beams. After the concrete has

* This system was illustrated and described in this journal for March, 1955.

Fig. 16.—Stadium at Budapest.

hardened the cables are tensioned by a force applied at right angles to their direction. An advantage of this arrangement is that, with a relatively small force, it is possible to produce considerable axial forces. In the Böröcz system (*Fig.* 20) the cables are also post-tensioned. Both ends of the cables are anchored at the same end and they are tensioned by means of a disc around which the cable is passed. In this way a good end anchorage is secured, and one disc suffices to tension what is in effect two cables. The Gnädig system has been applied to

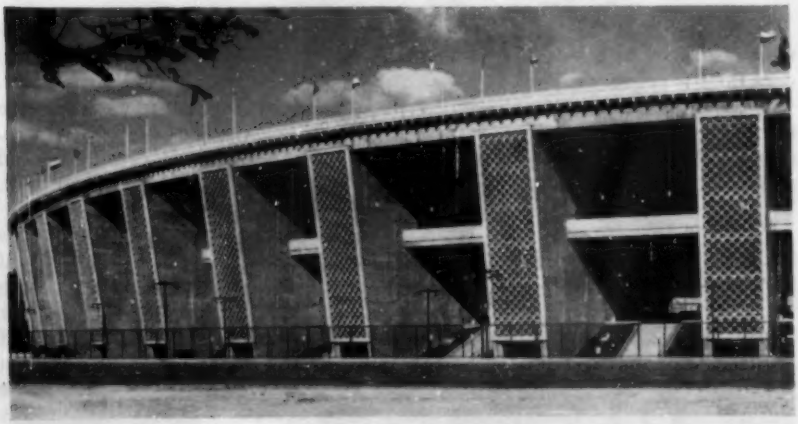


Fig. 17.—Stadium at Budapest.

Fig. 18.—A Prestressed Bridge.

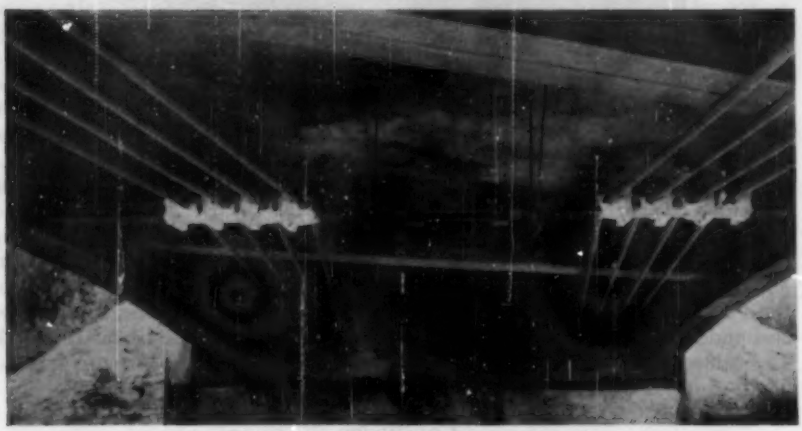


Fig. 19.—The Gnädig-Thoma Method of Prestressing.

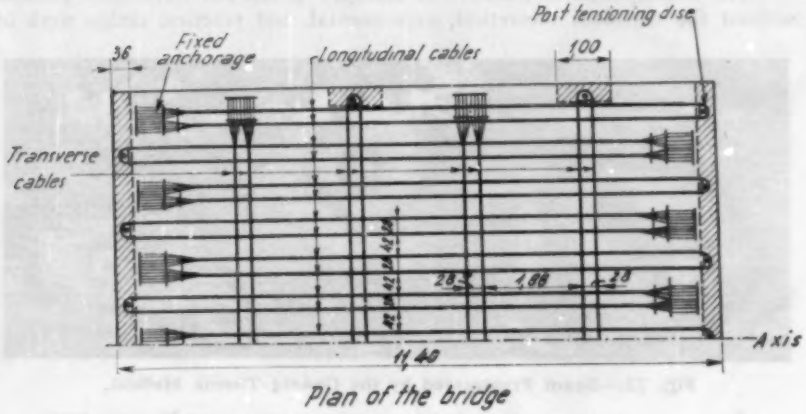


Fig. 20.—The Böröcz System of Prestressing.

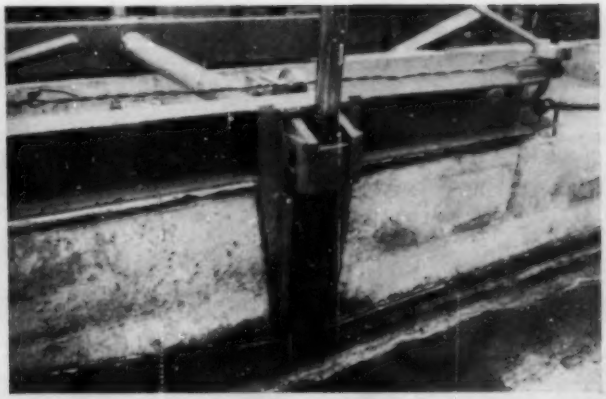


Fig. 21.—Tensioning Wires of a Prestressed Beam.

the construction of bridges, oil-storage tanks and precast beams. *Figs.* 21 and 22 show the method of prestressing precast beams by forcing the central parts of external cables in a downward direction and securing them in that position.

Prestressing has been advantageously used for the strengthening and widening of reinforced concrete bridges, and the load-carrying capacity has been increased by this means. For example the reinforced concrete cross-beams of a bow-string bridge have been strengthened by the Gnädig-Thoma method by pulling together, on the axis of the bridge, prestressing cables anchored in blocks at both ends of the cross beams. The main beams of a smaller bridge were strengthened by cables laid under the transverse beams and anchored in the end cross-beams (*Fig.* 23). The cables were extended by electrically-developed heat ; a difference in temperature of 56 deg. C. was sufficient to produce the required extension.

Conclusion.

The development of concrete in Hungary would not have been possible without the strenuous theoretical, experimental, and practical design work of

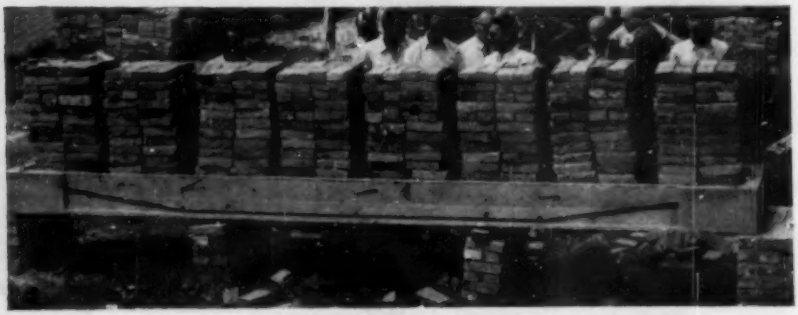


Fig. 22.—Beam Prestressed by the Gnädig-Thoma Method.

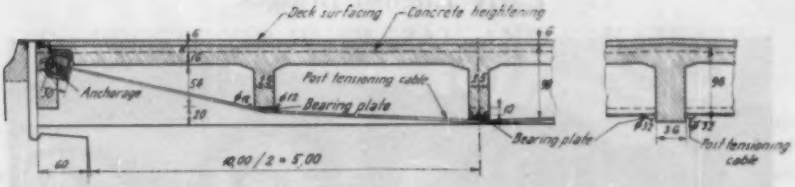


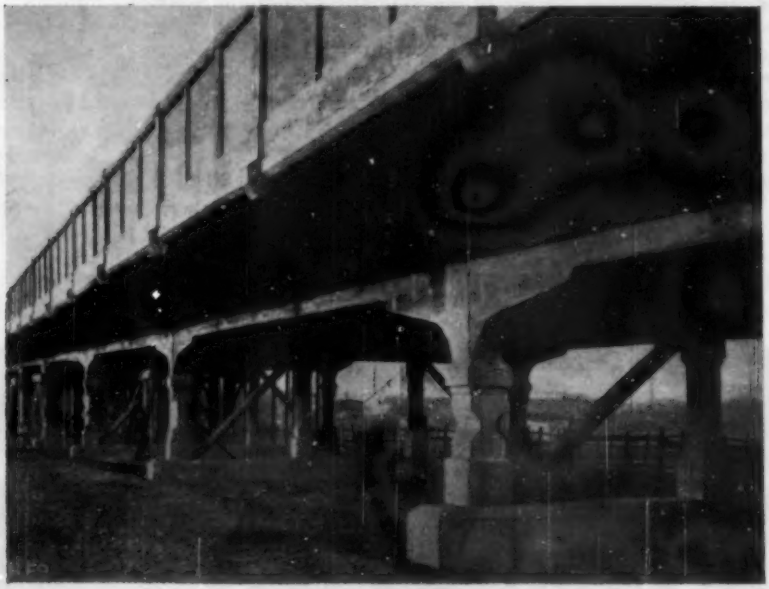
Fig. 23.—Strengthening a Reinforced Concrete Bridge by Prestressing.

Hungarian engineers. After the pioneer work of Professor Zielinski, Mr. Mihailich, and Mr. Kossalka, the theoretical results obtained by Dr. G. Kazinczy on the plastic behaviour of reinforced concrete structures, by Dr. Menyhárd, Professor Csonka and Mr. Szmodits on the theory and design of reinforced concrete shells, and by Mr. Sajó, Mr. Lampl, and Dr. Palotás on the composition and behaviour of concrete, and the work on structural design of Dr. Schwertner, Dr. Haviár, and Dr. Korányi are very remarkable and contributed greatly to the progress of concrete.

Finally I should like to mention the outstanding work of Hungarian authors, which has assisted in the widespread use of reinforced concrete, and also the part played by "Concrete and Constructional Engineering" in so successfully helping to develop the use of concrete throughout the world.

Concrete Bridge at Leadon, Devon. Built in 1877.

[It was intended by Philip Brannon, the engineer, to cross the river with one span of 100 ft., but this was not permitted by the authorities, and two 30 ft. spans and one 50 ft. span were built. The bridge is still in good condition and in use.]



Viaduct in East London. Built in 1907.

[Seventeen spans of 43 ft. Designed as continuous girders. Roadway 24 ft. wide; two footpaths each 2 ft. wide. Deck 6 in. thick. Designed for a dead load of 192 lb. per square foot and a live load of 800 lb. per square foot.]

POLAND

By PROFESSOR W. OLSZAK AND S. KAJFASZ

WARSAW.

THE first reinforced concrete structures were erected in Poland in the years 1892–1894. These were arches of 8 m. and 11 m. (26 ft. and 36 ft.) span, one of which, designed by Professor M. Thullie, was built at the Lwów Institute of Technology. The first cement works in Poland were built in 1855–1857 at Żelechow, Grodziec, and Będzin. Many more cement works were built in 1872–1889, and in 1892 Poland had one of the biggest cement industries in Europe, with a production of 65,000 tons of high quality cement.

The early development of reinforced concrete in Poland is associated with the name of Maksymilian Thullie who, in the years 1894–1939, was Professor at the Lwów Institute of Technology. He worked on the theory of reinforced concrete structures and popularised the new material in articles published in " Czasopismo Techniczne " (" Technical Magazine ") as well as in foreign scientific

Fig. 1.—Reinforced Concrete Bridge Built in 1904.

magazines, especially German ; for this reason Thullie is often mistakenly referred to as a German scientist. In 1903 he published his book " Mosty Sklepione " (" Arch Bridges "), in which he devoted much space to reinforced concrete bridges. Thullie's experiments on the strength of reinforced concrete columns from 1906 to 1912 were fundamental, and have been generally accepted throughout the world. Other Polish scientists were also interested in reinforced concrete, and in 1905 papers on the calculation of reinforced concrete structures were published in the " Technical Magazine " by Professor M. T. Huber.

Structures Built before 1914.

The application of reinforced concrete to bridges began in 1902–1906, when forty-five bridges of the Hennebique type, having spans from 6 m. to 70 m. (20 ft. to 230 ft.) were built. Bridges up to 13 m. (43 ft.) span were beam and slab structures ; for larger spans lattice girders or arches were used. *Fig.* 1 shows a

Fig. 2.—Bridge Built in 1904.

bridge of 24 m. (79 ft.) span with a road 6 m. (20 ft.) wide built in 1904. Another bridge, built at Nowy Sacz in the same year, has two 30-m. (99-ft.) spans, with a rise of 3·4 m. (11 ft.) and a road 7·5 m. (25 ft.) wide. A bridge over the Jasiolka river near Krosno has two spans of 20·5 m. (67 ft.) and one of 25 m. (82 ft.), with a rise-span ratio of 1 : 10 ; the bridge (*Fig.* 2) was erected in 70 days. A bridge at Olszany, with spans of 11 m. (36 ft.), 13 m. (43 ft.) and 11 m. (36 ft.), and a width of 6 m. (20 ft.), built in 1904, is a continuous-beam structure with transverse stiffeners. The quantities of materials used were 1·8 cu. m. of concrete per metre of span and 170 kg. of steel per cu. m. (19½ cu. ft. per ft. and 286 lb. per cu. yd.).

About the year 1905 arch bridges (*Fig.* 3) were also built over rivers in deep valleys. For example, the river Rybnica was crossed by arches with spans of 17 m. (56 ft.) and 18 m. (59 ft.), at a height of 17 m. (56 ft.) above the river. The shuttering was supported by pillars, a method that was economical in timber and also ensured safety against the great fluctuations of the water level experienced in rainy periods. The depth of the arch at the springings is 60 cm. (2 ft.) and at the crown 30 cm. (1 ft.). The amount of reinforcement was 92 kg. per cu. m. of concrete (155 lb. per cu. yd.). The work was finished in 115 working days. A bridge which, owing to its length, was for a long time the most important concrete structure in Poland, is the five-span bridge (*Fig.* 4) over the Wisloka near Przeczyca ; it has four spans of 30·5 m. (100 ft.) and one of 38 m. (125 ft.).

Fig. 3.—Bridge Built in 1905.

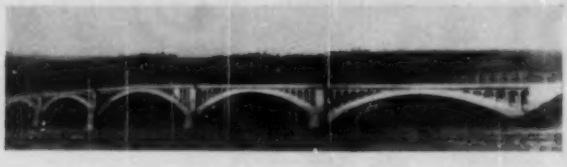


Fig. 4.—Bridge at Przeczyca.

Up to the outbreak of the first world war about 1500 reinforced concrete structures, including about 300 bridges, had been built in Poland. The Poniatowski bridge over the Vistula in Warsaw should be mentioned as a great achievement. This viaduct, designed by W. Paszkowski, is 702 m. (2300 ft.) long and was built between 1904 and 1914; it was the first work in which welding was used to join reinforcement in arches of 20 m. (66 ft.) span. In 1906 the first ten-story building with a reinforced concrete frame (the Cedergren building) was built.

Structures Built between 1919 and 1939.

Building was much hampered by the conditions prevailing after the first world war, and temporarily lagged behind the achievements of other countries. In 1919 Professors M. T. Huber and M. Thullie produced regulations and standards for reinforced concrete. New scientists (including S. Bryła, A. Kuryłło, B. Bukowski, and A. Chmielowiec, who all became known abroad) began to publish the results of their research, and W. Paszkowski worked on the technology of reinforced concrete and concrete mixtures.

Among many interesting bridges erected between 1924 and 1927 several deserve mention. The five-span arch bridge (*Fig.* 5) over the Soła river at Oświęcim, built in 1924, has a total length of 173 m. (568 ft.) and its longest span is 42 m. (138 ft.); the depth of the arch at the crown is 70 cm. (2 ft. 4 in.) and at the springings 116 cm. (3 ft. 10 in.). The piers and abutments are partly on well foundations and partly on caissons. In 1925 a bridge (*Fig.* 6) with spans of 51 m. (167 ft.) and 35 m. (115 ft.) was built over the Warta river at Poznań; the depth at the crown of the longer arch is 50 cm. (1 ft. 8 in.) and its rise-span ratio is 1 : 12. In 1925–1927 a bridge 180 m. (590 ft.) long, of the continuous type, was constructed over the Vistula near Goczałkowice. In 1928 a bridge with three continuous arches of 28 m. (92 ft.), 42 m. (138 ft.), and 28 m. (92 ft.) was built over the Vistula near Oświęcim. In 1930 an arch bridge with four spans of 60 m.

Fig. 5.—Bridge at Oświęcim.

(197 ft.) was built over the Pilica river near Białobrzegi; the piers were on well foundations.

A bridge over the Soła river at Tresna Czernichów, designed by Professor W. Burzyński, is typical of the bridges built after 1930. The deck is partially suspended from an arch of 76 m. (249 ft.) with a rise of 1 in 6. The arch ribs are 0·8 m. (2 ft. 7 in.) by 1·1 m. (3 ft. 7 in.) at the crown and 1·24 m. (4 ft. 1 in.) by 1·9 m. (6 ft. 3 in.) at the springings. The materials used were 430 cu. m. (556 cu. yd.) of concrete and 93 tons of steel. In the foundations there are 1670 cu. m. (2160 cu. yd.) of concrete. The stress permitted in the concrete was 70 kg. per sq. cm. (996 lb. per sq. in.). The bridge was completed in 180 days in 1934, and had the longest span in Poland; it was destroyed during the second world war.

In 1926–1930 reinforced concrete was used in all branches of civil engineering, particularly tall framed structures, for example the ten-story students' hostel in Warsaw and the Mutual Insurance Company's building. The quantity of concrete used for a 6-story building for the Bank of National Economy was 15,000 cu. m. (19,500 cu. yd.). An interesting industrial building is a silo 13 m. (43 ft.) diameter

Fig. 6.—Bridge at Poznań.

and 28 m. (92 ft.) high, designed by Professor B. Bukowski for the Solvay factory at Kraków, with a charging slope 10 m. (33 ft.) high, also of reinforced concrete.

Reinforced concrete is also widely used in mining and metallurgy. In coal mines the linings of many pits and galleries are of concrete or reinforced concrete, as are shaft bottoms on poor soil and subjected to great pressures and loads. Reinforced concrete pipes for pressures of 20 to 50 atmospheres are also used in mines.

In the construction of the port at Gdynia,* which at that time was one of the most up-to-date in the world, reinforced concrete caissons were used as foundations for quay walls; they were made on shore and towed to the place of sinking. All the sheds are framed structures, and the silos, elevators, water-cooling plant and the harbour station, with a multiple-span shell roof, have been built in reinforced concrete. The grain elevator is a 9-story framed structure measuring 70 m. (230 ft.) by 21 m. (69 ft.) by 30·6 m. (100 ft.) high on cast-in-situ piles.

Between 1929 and 1932 a dam 26 m. (85 ft.) high and 200 m. (656 ft.) long,

* See "Concrete and Constructional Engineering", September 1929.

containing 70,000 cu. m. (91,000 cu. yd.) of concrete, was built on the Wapienica river. The concrete plant had a capacity of 600 cu. m. (783 cu. yd.) a day. The Soła dam (*Fig.* 7) at Porabka, built between 1934 and 1937, is 260 m. (852 ft.) long and has a maximum height of 38 m. (125 ft.); it contains about 100,000 cu. m. (130,000 cu. yd.) of concrete. Between 1935 and 1940 a dam 550 m. (1810 ft.) long by 50 m. (164 ft.) high, and containing 400,000 cu. m. (525,000 cu. yd.) of concrete was built at Różnów on the Dunajec river; this is the largest hydraulic structure in Poland. The concrete plant had a capacity of about 2000 cu. m. (2620 cu. yd.) of concrete per 24 hours. Two mixers with batch capacities of 1·6 cu. m. (2 cu. yd.) were used, and the concrete was transported on overhead cables in two spans of about 300 m. (985 ft.) each.

Shell roofs of the Zeiss-Dywidag type, based on a theory developed in 1934 by W. Zenczykowski, came in use during the period, and roofs of railway platforms, sheds, and market halls were built on this system. High-strength ribbed bars were used (e.g. Griffel) and research on concrete reinforced with special steels was done by S. Bryła and M. T. Huber. Research on vibrated concrete started at the Institute for Road Research in Warsaw in 1936, B. Bukowski was

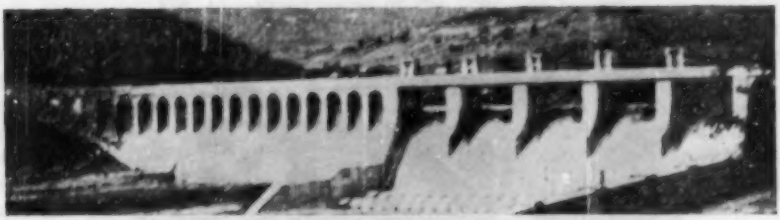


Fig. 7.—The Soła Dam.

investigating an accelerated test for concrete, and many works on reinforced concrete were published by J. Nechay. In 1929 the Cement Board, comprising representatives of concrete design and construction, was formed. Two sessions were held to summarise the country's achievements in reinforced concrete construction, one in Warsaw in 1931 and the other at Katowice (now Stalinogród) in 1936. The aim of the meetings was to provide an opportunity for engineers to discuss their problems.

From 1945 Onwards.

The second world war not only stopped construction, but largely destroyed pre-war achievements. After the Liberation the country was so badly ravaged that reconstruction was the prime object, and the Three-years' Plan was started. Intense residential and industrial building followed, and the work was organised as State building enterprises. In 1950–1955 large industrial expansion began under the Six-years' Plan. The reconstruction of the country and the development of industry are on such a large scale that new methods and processes have to be devised. Prefabrication becomes more and more popular, mainly, for columns and roof trusses of industrial buildings. Emphasis is placed on economy in steel

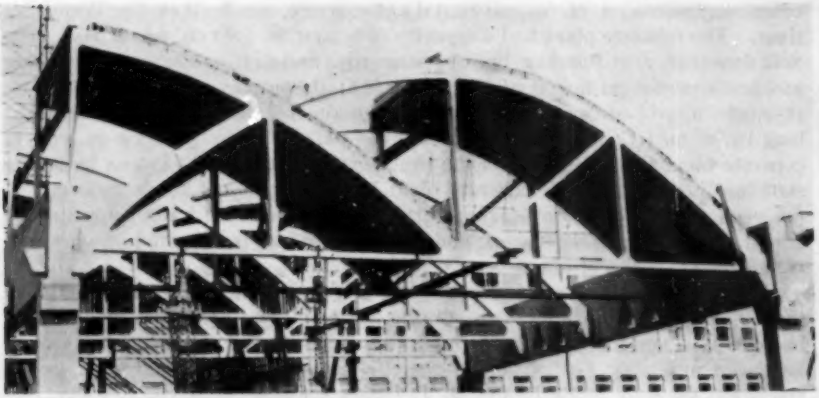


Fig. 8.—New Type of Roof.

Fig. 9.—Floor Construction for Houses.

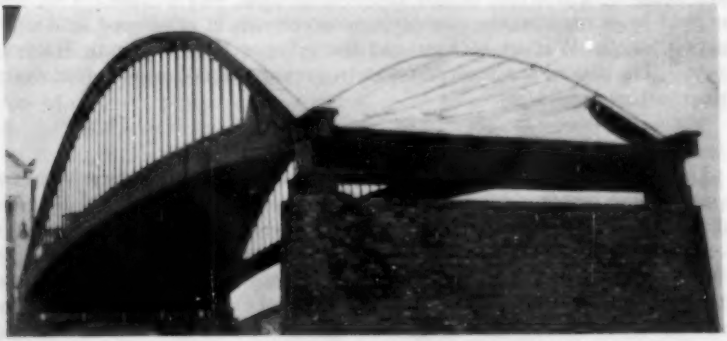


Fig. 10.—Shell Roof at Engine Sheds.

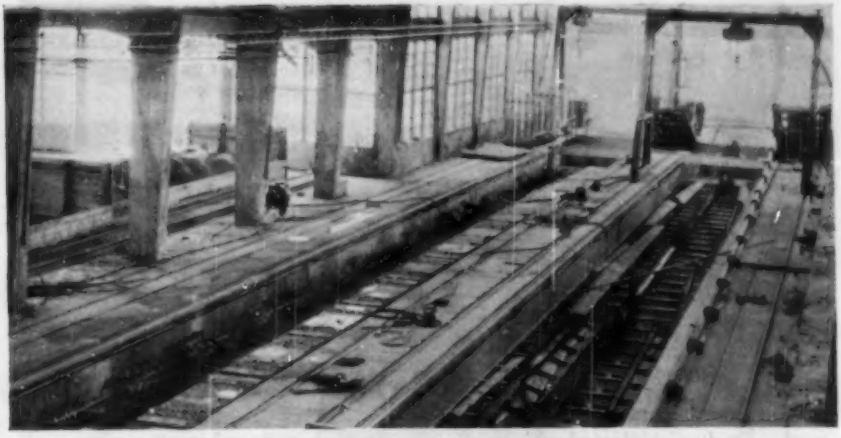


Fig. 11.—Prestressing on the Long-line System.

and quick construction, and many types of roofs (*Fig.* 8) have been produced. For houses the mass production of floors made of beams and hollow blocks (*Fig.* 9) should be mentioned, brick rubble from bombed buildings often being used as aggregate. New types of shell roofs have been designed, for example, a conoidal saw-tooth roof of 25 m. (82 ft.) span, 7 m. (23 ft.) wide and 6 cm. (2⅜ in.) thick for engine sheds (*Fig.* 10). Saw-tooth roofs on columns on a grid 12 m. (39 ft.) square are also used on a large scale, as are precast elements.

In view of the hard climate, research on steam curing has been started. Columns and roofs are covered with insulating matting and tarpaulin. Between the insulation and the concrete, steam is passed through perforated pipes. In the case of moving shutters heating elements are installed on the shuttering. A period of forty hours is generally sufficient for the concrete to harden sufficiently so that it will not be harmed by frost. The process of raising the temperature to 70 deg. to 75 deg. C. requires eight to ten hours, followed by four to six hours of curing and ten to eighteen hours of cooling. Temperature control by thermo-couples has been developed.

The concrete industry has undergone a great evolution. Construction work has been mechanised, aggregates are measured by weight, the framework of the reinforcement is sometimes assembled complete before the concrete is placed, and steel moulds ensure that dimensions are exact in precast work.

Prestressed Concrete.

Lack of information on foreign achievements during the occupation and the first years of reconstruction caused serious delays in the adoption of prestressed concrete. A considerable amount of theoretical work was done between 1946 and 1949; in 1950 the first prestressed concrete works, working on the long-line system with pre-tensioned wire, was started, and other factories followed. Production lines of 50 m. (164 ft.), or, more seldom, of 100 m. (328 ft.) (*Fig.* 11) were

Fig. 12.—Prestressing Large Beams.

used. Production started with small elements, such as floor beams, purlins, and railway sleepers, followed by elements such as I-section roof trusses from 50 cm. (1 ft. 8 in.) to 80 cm. (2 ft. 8 in.) deep, and finally to elements 15 m. (49 ft.) long and 5 tons in weight (*Fig.* 12). An example of the use of these trusses is shown in *Fig.* 13.

Railway sleepers are produced in large numbers, and sleepers with an increased electrical resistance for electrified lines are being studied. Prestressed concrete poles for electrified lines (*Fig.* 14) are also made, as well as prestressed piles. In the pre-tensioning process wires of 2·5 mm. are used with a tensile strength of 220 kg. per sq. mm. (314,000 lb. per sq. in.), and twisted and undulating wires are

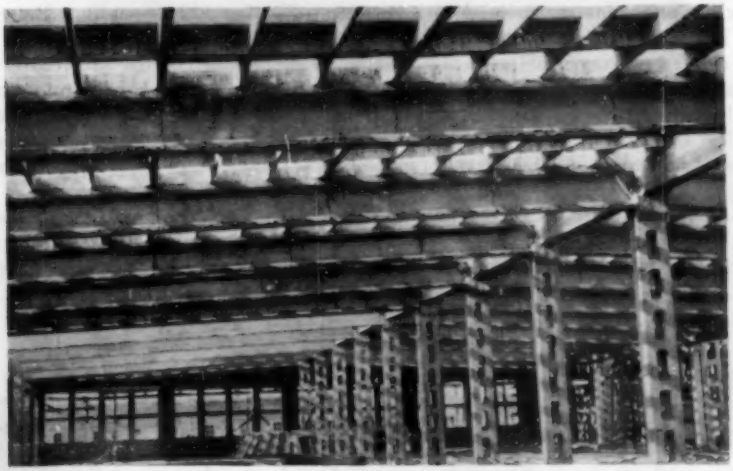


Fig. 13.—Prestressed Roof Trusses.

also used. In the post-tensioned steel process, two types of jacks, somewhat similar to the Freyssinet jacks, have been produced for tensioning twelve 5-mm. wires at a time, as well as jacks for tensioning pairs of wires (the Magnel process). Two kinds of anchors (steel and reinforced concrete) have been designed (T. Kluz). All this work lasted nearly four years. The strength of the 5-mm. wire for post-tensioned structures varies between 140 and 165 kg. per sq. mm. (200,000 and 236,000 lb. per sq. in.).

Prestressed concrete with post-tensioned steel is most widely used in bridges. The first slab bridges of 12 to 17 m. (39 ft. to 56 ft.) span were built in 1952 at Końskie and Batowice. For longer spans H-shape prestressed beams and reinforced concrete slabs are used. One of the larger structures, a road bridge near

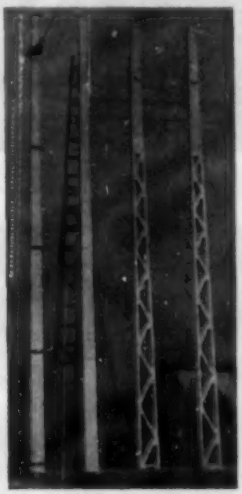


Fig. 14.—Transmission-line Poles.

Bydgoszcz designed by M. Bieniek and built in 1953, has two spans of 14·7 m. (48 ft.) and one of 33 m. (108 ft.) and a construction depth of 2·05 m. (6 ft. 9 in.). It is a prestressed girder structure.

So far the largest prestressed structure is the roof (*Fig.* 15), comprising two continuous slabs each 42·4 m. by 63 m. (139 ft. by 207 ft.) of varying thickness, designed by Z. Wasiutyński. The slabs rest on columns spaced 19·2 m. (63 ft.) by 12 m. (39 ft.) apart. The working load is 2·2 tons per sq. m. (450 lb. per sq. ft.). The shape of the underside of the roof is the result of the intersection of barrel vaults. The slabs are 28 cm. (11 in.) thick at the crown and 110 cm. (3 ft. 7 in.) at the supports. They are designed as beamless floors and prestressed with cables in two directions (*Fig.* 16), the necessary eccentricities being obtained by varying the thickness of the slabs. Each slab is built in five strips, each strip being prestressed in its length; *Fig.* 17 shows part of the roof. The prestressing in the other direction was done after all the strips were concreted and the expansion

Fig. 15.—A Prestressed Roof.

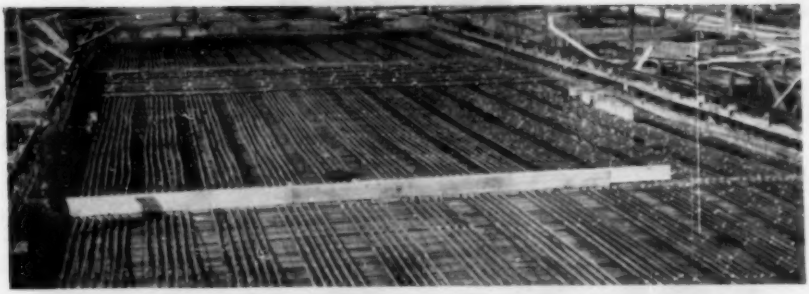


Fig. 16.—Prestressing Cables for Roof shown in Fig. 15.

Fig. 17.—Part of Roof.

Fig. 18.—Travelling Roof Centering.

joints made. The slabs comprise 2400 cu. m. (84,600 cu. ft.) of concrete. Travelling centres were used (*Fig.* 18), and low-pressure steam curing was applied (*Fig.* 19).

Apart from bridges, prestressed concrete with post-tensioned steel is most widely used for the roofs of industrial buildings. Solid I-shape trusses of 16 m., 18 m., and 21 m. (53 ft., 59 ft., and 69 ft.) were first used, but these have been replaced

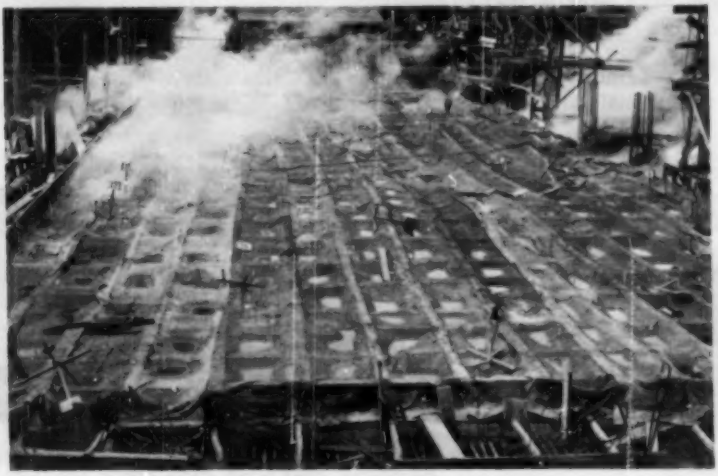


Fig. 19.—Steam-curing on Roof.

Fig. 20.—Prestressed Trusses.

by lattice trusses in the form of tied arches. The usual weights are as follows: Span 18 m. (59 ft.), weight 3½ tons; span 21 m. (69 ft.), weight 6·2 tons; span 24 m. (79 ft.), weight 7·9 tons; span 30 m. (98 ft.), weight 11·7 tons. Trusses of less than 24 m. (79 ft.) have so far been made in one piece (*Fig.* 20). Trusses 30 m. (98 ft.) long are now composed of separate triangular elements prestressed together on the site (*Fig.* 21) so that they can be cast in a factory. Prestressed cantilevered trusses are shown in *Fig.* 22. New types of prestressed tunnel linings have recently been designed.

Theoretical Problems.

In designing reinforced concrete the calculations are now almost exclusively by the ultimate-load method. The theory of linear stress distribution is also

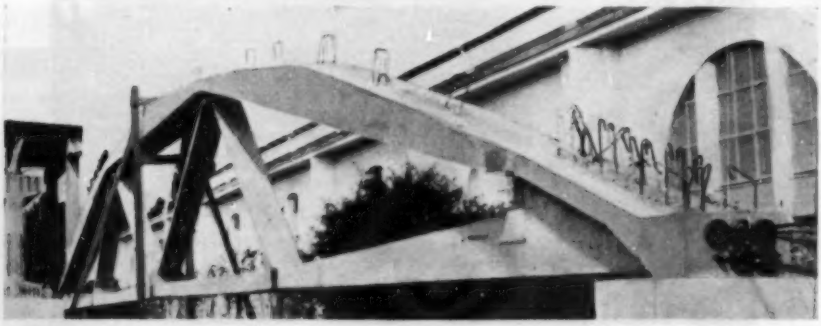


Fig. 21.—Prestressed Truss made in Three Parts.

accepted in a modified form, so as to give the same cross sections as in ultimate-load design.

Problems of the ultimate strength of framed structures, which are the basis of the Polish standard specifications, play an important part in the present research of B. Bukowski, and the non-linear properties of materials were considered by S. Hempel. However, the principal research is on the theory of elasticity and plasticity applied to one-dimensional, two-dimensional, and three-dimensional problems, with the aim of more nearly approaching actual conditions and correct determination of stresses and deformations, including the development of the theory of anisotropic plates in the elastic range. This work is being done by W. Nowacki and his co-workers, and relates to plates with various conditions of support and loading, and many original solutions have been obtained.

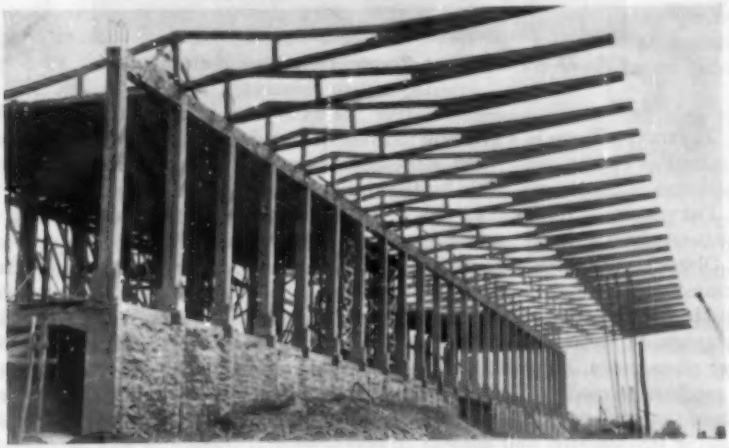


Fig. 22.—Prestressed Cantilevered Roof Trusses.

A fully-developed theory of the ultimate load-carrying capacity of plates, by W. Olszak and his co-workers, concerns singly and doubly (laminarly) orthotropic plates. To meet practical requirements this theory has been generalised to relate to non-homogeneous slabs. A simple mechanical analogy (of the "sand-hill" type) has been developed to supply information on the kinematics of the failure of complex types of structures. At present, a theory of the ultimate strength of tanks, flat slabs, and orthotropic shells is being developed. A theory of reinforcement in the form of grids has also been developed (see "Concrete and Constructional Engineering", 1948, p. 317).

In design based on ultimate strength, the choice of the factor of safety is important, and must be based on probability. Investigations on this question are being made, based on fundamental ideas of W. Wierzbicki published in 1936, and methods which have since been developed.

Fig. 23.—Transverse Compressive Test for Cylinders.

Research.

TESTING.—There is a growing interest in non-destructive methods of testing by means of elastic, sonic, and ultrasonic waves. It is intended to replace the tensile test of brittle materials by the transverse compressive test (*Fig. 23*).

PRESTRESSED CONCRETE.—In prestressed concrete spirally-bound columns have been given a theoretical basis, the spirals having a high degree of pre-tension (W. Olszak) ; the ultimate strength of such columns is much greater than that of columns with normal binding. New data (by S. Kaufman and C. Eimer) have been obtained on the stability of prestressed structures, and research on statically-indeterminate prestressed structures has been undertaken by S. Kaufman. Non-linear phenomena, in particular creep and relaxation, may be studied by means of a mechanical model (W. Olszak and J. Litwiniszyn) which enables the mechanics of these time-delayed phenomena to be studied. Reinforced prestressed members are being investigated and used in compression and tension as well as for soffits (T. Kluz, R. Kozak, W. Grzegorzewski, and W. Poniź).

A new method of producing prestressed precast elements is a continuous automatic process with a high rate of production. This method, which resembles a rolling process without prestressing beds, makes possible a greater variety of products and greater economy.

ORGANISATION OF RESEARCH.—The achievements of scientific research in Poland are largely due to the fact that it is all directed and partly controlled by the Polish Academy of Sciences, and activities that were formerly haphazard are planned and co-ordinated. Ten years have elapsed since the creation of the Institution of Structural Techniques, and one of its most important departments is that relating to concrete. Research on concrete is also carried on at all the institutes of technology.

The development of theory and practice seems to indicate two ways for the progress of concrete structures. One is prefabrication, which is economical, facilitates speedy building, and eliminates seasonal work. The other is pre-stressing, which encourages the use of materials of the highest quality. The fine traditions of reinforced concrete in Poland inspire hope for its future.

AUSTRIA

By PROFESSOR FRIEDRICH BARAVALLE

VIENNA.

WHEN Monier made his patents available in other countries, Rudolf Schuster of Vienna in 1885 acquired the sole rights of this method of construction in Austria. From him Gustav Adolf Wayss bought the rights for Austria, and also acquired the German rights from the firms of Martenstein & Josseaux, and Freytag & Heydschuh. In collaboration with Bauschinger, Conrad Freytag, and Koenen, Wayss made the first tests of reinforced concrete in Austria, the results of which were given in " The Monier System : Steel Reinforcement Embedded in Cement ". As a result of these tests the first method of designing reinforced concrete was published in 1886 in " Zentralblatt der Bauverwaltung ". Extensive research followed by the Austrian Select Committee for Reinforced Concrete on behalf of the Society of Austrian Engineers and Architects.

Ludwig Paul Roth, a civil engineer, was instrumental in establishing the Committee for Reinforced Concrete in 1906 and, in collaboration with the Austrian Concrete Institute, founded in 1907, extensive testing and research were commenced under the guidance of many distinguished pioneers including Wayss and his collaborators, Josef Anton Spitzer, Rudolf Schuster, Viktor and Benno Brausewetter, Rudolf Saliger, Fritz Emperger, Ludwig Paul Roth, Franz Visitini, and many more. These men are remembered because their work was of great influence not only in Austria but throughout the world.

In 1909 the first code of practice for reinforced concrete design in buildings was issued by the Austrian Concrete Institute. The development of reinforced concrete was furthered by research on improving the quality of concrete and reinforcement, ensuring reliable strengths of materials, investigating the resistance of concrete to shearing and the bond between concrete and steel, the prevention of cracks, and the provision of more accurate methods of calculation. Of these investigations the following are particularly noteworthy : Tests on arches, by the Austrian Society of Engineers and Architects, Tests on safety against fire, lightning, and rust (1908–1912), Tests on resistance to shearing and bond (1913–1914), and Tests on the strength of reinforced concrete beams with mild steel bar reinforcement.

Based on these tests, the Austrian Committee for Codes of Practice issued " Regulations for the Calculation and Construction of Reinforced Concrete ", and the Ministry for Public Works (later the Federal Ministry for Commerce, Trade, Industry, and Building) published " Regulations for Plain and Reinforced Concrete Construction ". Up to 1936 these codes and regulations were repeatedly revised. They retained, however, the theory of elasticity as the basis of calculation, that is the permissible stress was subject to the assumption of the moduli E_c for concrete and E_s for steel. The modular ratios required were 10 where no tensile stresses are developed (state I), and 15 where tensile stresses are developed (state II). Subsequent research included studies on the behaviour of columns subjected to compression only, beams and slabs subjected to bending only, and members subjected to eccentric loading.

Columns.

After many years of research on the strength of columns reinforced with mild steel, structural steel, and high-grade steel with or without spiral reinforcement, Professor Rudolf Saliger (Professor of Reinforced Concrete and the Theory of Structures at the University of Vienna) investigated from 1909 to 1940 the conditions causing failure of reinforced concrete columns. The knowledge that the maximum load depended upon the compressive strength of the concrete and steel, and that failure occurred only upon the failure of both concrete and steel, led to a new method of calculation, the so-called theory of plasticity, or ultimate-load method of design.

Instead of the customary permissible load $\frac{1}{R_L}(A + mA_e)c$, a new permissible load $\frac{1}{R_L} \cdot \frac{1}{FS}(Ac_p + A_e t_y)$ was introduced, R_L being the reduction factor for buckling, A the cross-sectional area of the concrete, A_e the cross-sectional area of the longitudinal steel, c the permissible stress according to the theory of elasticity ($m = 15$ in Austria), c_p the crushing strength of a prism, t_y the yield of the reinforcement, and FS the factor of safety. With this method of calculation there were possibilities of using with economy higher grades of concrete and steel, particularly in columns. A comparison of the permissible loads on a column from the beginning of the century to the present day is illustrated in the following example.

Assume a column 50 cm. by 50 cm. (1 ft. 8 in. by 1 ft. 8 in.) in cross section and 5 m. (16 ft.) high with a minimum percentage of reinforcement.

$$\mu_{min.} = \frac{A_e}{A} = 0{\cdot}008, \quad A_e = 20 \text{ sq. cm.}, \quad \text{and } m = 15.$$

REGULATIONS OF 1909 (*Elastic Theory*).—Permissible load, $\frac{1}{R_L}(A + mA_e)c$.

$\lambda = \frac{L}{g} = \frac{500}{14{\cdot}4} = 35$; hence $R_L = 1$.

Max. $c = \frac{\text{max. } c_u \cdot 28}{10} = \frac{200 \text{ kg. per sq. cm.}}{10} = 20$ kg. per sq. cm.

Permissible load: $\frac{1}{1}(50 \times 50 + 15 \times 20) \times 20 = 56{,}000$ kg. $= 56$ *tonnes.*

REGULATIONS OF 1936 (*Elastic Theory*).—Permissible load, $\frac{1}{R_L}(A + mA_e)c$.

$\lambda = \frac{L}{g} = \frac{500}{14{\cdot}4} = 35$; hence $R_L = 1$.

Max. $c = \frac{\text{max. } c_u \cdot 28}{3{\cdot}5} = \frac{263}{3{\cdot}5} = 75$ kg. per sq. cm.

Permissible load: $\frac{1}{1}(50 \times 50 + 15 \times 20) \times 75 = 210{,}000$ kg. $= 210$ *tonnes.*

REGULATIONS OF 1938 (*Plastic Theory*).—Permissible load, $\frac{1}{R_L} \cdot \frac{1}{FS}(Ac_p + A_e t_y)$.

$\lambda = \frac{L}{g} = \frac{500}{14{\cdot}4} = 35$; hence $R_L = 1$.

Max. $c_p = 240$ kg. per sq. cm.; Max. $t_y = 3600$ kg. per sq. cm. $FS = 3$.

Permissible load: $\frac{1}{1} \times \frac{1}{3}(50 \times 50 \times 240 + 20 \times 3600) = 224{,}000$ kg.

$= 224$ *tonnes.*

Regulations of 1953 (*Plastic Theory*).—Permissible load, $\frac{1}{R_L} \cdot \frac{1}{FS}(A_c \sigma_p + A_s \sigma_y)$.

$\lambda = \frac{L}{g} = \frac{500}{14{\cdot}4} = 35$; hence $R_L = 1{\cdot}075$.

Max. $\sigma_p = 300$ kg. per sq. cm. Max. $\sigma_y = 4200$ kg. per sq. cm. $FS = 2{\cdot}5$.

Permissible load: $\frac{1}{1{\cdot}075} \cdot \frac{1}{2{\cdot}5}(50 \times 50 \times 300 + 20 \times 4200) = 310{,}000$ kg.

$= 310$ *tonnes.*

Table I gives the permissible loadings on plain and reinforced concrete columns for different strengths of concrete, grades of steel, and percentages of reinforcement, as provided in Austrian codes. It is seen that, within the limits of the codes of practice, unreinforced columns in this example may carry a load of 12·5 tonnes to 94 tonnes, and reinforced columns loads varying from 130 tonnes to 516 tonnes.

Beams.

With the introduction of Isteg bars (which comprise two mild steel bars twisted together while the ends are held firmly in position), developed in 1927 by the Viennese industrialist Herr Hoffman and Herr Umlauf, the way was opened for the invention of Torstahl by Rudolf Schmidt (Schmidtstahlwerke A.G., Vienna), who in 1935 developed a cold process of twisting single bars so that the increased strength of the bar extended uniformly over its whole length, which might be 100 m. (330 ft.) or more. By twisting the bar about its own axis the

Table I.—Permissible Loads on Columns.

Section 50 cm. × 50 cm. Length 5 m.		Grade of Concrete						
		B 50	B 80	B 120	B 160	B 225	B 300	B 400
		Permissible Load (Tonnes)						
Plain Concrete Permissible Load = $\frac{1}{\alpha} A_c$ ($\alpha = 2$)		12·5	25	37·5	50	68·5	94	
Reinforced Concrete Minimum Reinforcement $\mu_{min} = 0{\cdot}008$, $W = 1{\cdot}075$ Permissible Load = $\frac{1}{2{\cdot}5W}(A_c \sigma_p + A_c \sigma_s)$	*				130	176	228	298
	†				140	186	238	308
	‡					190	242	312
Reinforced Concrete Maximum Reinforcement For B 160 $\mu_{max} = 0{\cdot}03$ " B 225 " = 0·04 " B 300 " = 0·05 " B 400 " = 0·06	*				180	284	322	415
	†				216	298	384	487
	‡					316	406	516

* Concrete/Steel Group I Steel Quality: St. 37 S or T

† " " " III " " : Torstahl 40

‡ " " " V " " : Torstahl 60

Note: $W = R_L$ $\sigma_p = c_p$, and $\sigma_s = t_y$ in text.

Fig. 1.—Marien Bridge, Vienna: Main Span of 186 ft.

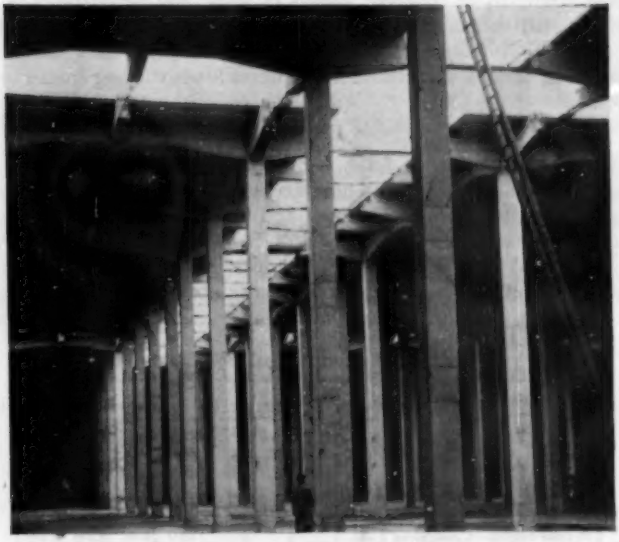


Fig. 2.—Reservoir of 132,000,000 Gallons Capacity.

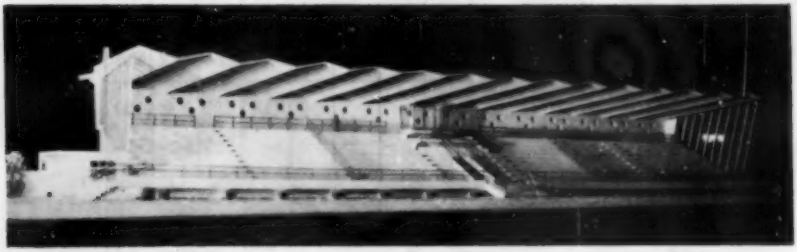


Fig. 3.—Sports Stand at Wattens: Cantilevers of 43 ft.

yield-point stress was eliminated. Steel made in this manner has a continuous stress-strain line, a fact of particular advantage in high-tensile steels where each increase of deformation is preceded by an increase of strength.

The development of cold deformed bars may be summarised as follows: Ordinary mild steel (Betonstahl I, St. 37) could be stressed to 1200 kg. per sq. cm. (17,100 lb. per sq. in.) up to the year 1937, and to 1400 kg. per sq. cm. (20,000 lb. per sq. in.) after 1937. A separate code permitted Isteg bars to be stressed to 1700 kg. per sq. cm. (24,200 lb. per sq. in.). Torstahl was initially produced from mild steel (Betonstahl I, St. 37), and twisted to a pitch of only 15 diameters, so as to guarantee a minimum yield-point stress of 3600 kg. per sq. cm. (51,000 lb. per sq. in.) and was designated "Torstahl 36". An appendix to the Austrian Code of 1936 included Torstahl among the high-grade steels. Accordingly, the

Fig. 4.—Diving Stage at Schwaz, Tyrol.

permissible tensile stresses in simple bending were raised to 1800 kg. per sq. cm. (25,600 lb. per sq. in.) and for bending combined with axial forces to 2000 kg. per sq. cm. (28,500 lb. per sq. in.).

This, however, was only a beginning, and further tests with increased twisting showed that the yield-point stress could be increased to 4500 kg. per sq. cm. (64,000 lb. per sq. in.) when the pitch of the twist was 8 diameters, and the Vienna City Council in 1938 permitted the use of Torstahl 40 having a minimum yield-point stress of 4000 kg. per sq. cm. (57,000 lb. per sq. in.) and a pitch of 10 diameters. The permissible stresses were increased to 2000 kg. per sq. cm. (28,500 lb. per sq. in.) for bending only, and to 2200 kg. per sq. cm. (31,300 lb. per sq. in.) for bending combined with axial forces. In 1946 and 1948 respectively the Vienna City Council allowed, for Torstahl 40, an increase in stress to 2400 kg. per sq. cm. (34,200 lb. per sq. in.) for all constructional members made with higher-grade concrete.

Further investigations at the Eidgenössische Material Prüfungsanstalt, Zürich, indicated the possibility of even higher stresses being allowed. The Vienna City Council in 1949 recognised Torstahl 60 with a yield-point stress of

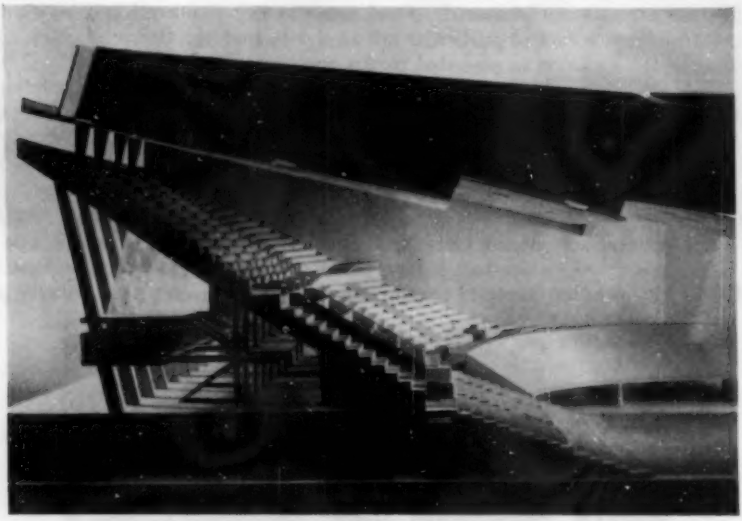


Fig. 5.—Municipal Hall, Vienna.

6000 kg. per sq. cm. (85,300 lb. per sq. in.). This permitted a stress of 3500 kg. per sq. cm. (50,000 lb. per sq. in.) in all members made with concrete of grade B225 or stronger. The latest development is Torstahl 80, and the Vienna City Council last year permitted in this steel a stress of 4700 kg per sq. cm. (67,000 lb. per sq. in.). In prestressed concrete the permissible stresses in Torstahl 80 are 5000 kg. per sq. cm. (71,000 lb. per sq. in.) at full prestress and 6400 kg. per sq. cm. (91,000 lb. per sq. in.) during prestressing. To-day, Torstahl is supplied in the following grades: No. 40, $t_y = 4000$ kg. per sq. cm. (57,000 lb. per sq. in.); $t_u = 1{\cdot}1 \times t_y$. No. 60, $t_y = 6000$ kg. per sq. cm. (85,300 lb. per sq. in.); $t_u = 1{\cdot}1 \times t_y$. No. 80, $t_y = 8000$ kg. per sq. cm. (114,000 lb. per sq. in.); $t_u = 9000$ kg. per sq. cm. (128,000 lb. per sq. in.).

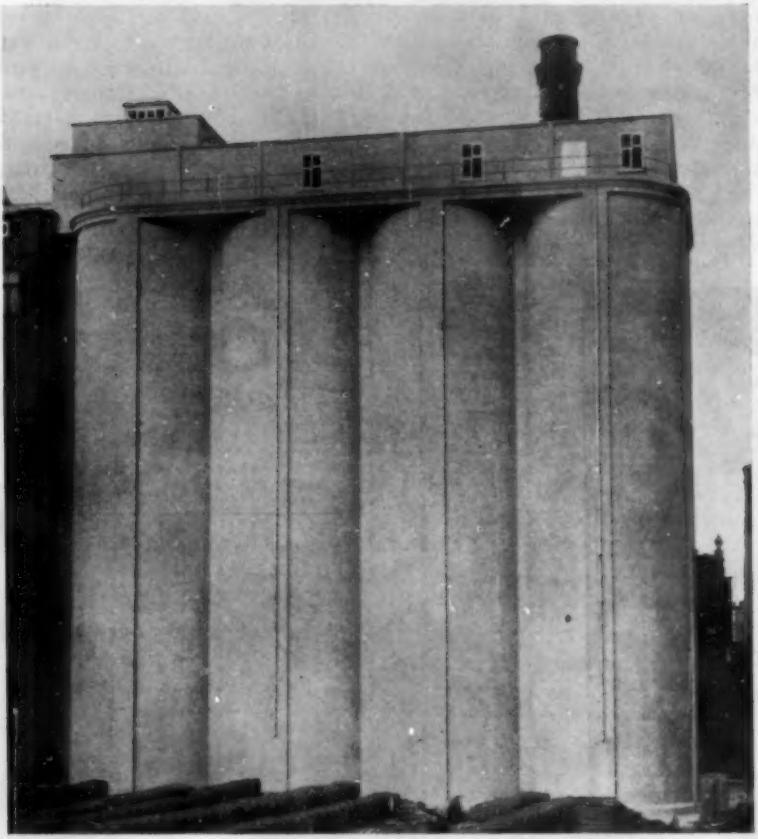
There are two ribs on the bar which, after twisting, have a helical shape with a pitch of 10 diameters. This feature, in conjunction with its stress-strain behaviour, ensures sufficient bond strength to enable these high stresses to be present, subject to the concrete having sufficient strength, without the formation of wide cracks. In Austria about 80 per cent. of reinforced concrete structures are reinforced with Torstahl 40 or 60, and Torstahl 80 is used predominantly for prestressed structures.

Prestressed concrete has great possibilities which Austrian engineers fully recognise. It results in considerable saving in weight and steel, and has many advantages which so far are not fully realised. Of the great number of reinforced concrete structures recently erected in Austria, some examples are illustrated in *Figs.* 1 to 6, which it is hoped may give an idea of the high standard of reinforced concrete in Austria. *Fig.* 1 shows the Marien bridge over the Danube canal at Vienna. The main span is 56·8 m. (186 ft.) long and the side spans 11·3 m.

(37 ft.) and 11·7 m. (38 ft. 5 in.). The reinforcement was welded into continuous lengths. The reservoir shown in *Fig.* 2 has a capacity of 600,000 cu. m. (132,000,000 gallons), and is 11 m. (36 ft.) deep. The stand at the sports ground at Wattens, Tyrol (*Fig.* 3), is 65 m. (213 ft.) long, and the roof is cantilevered 13 m. (43 ft.). *Fig.* 4 is a diving stage, 10 m. (33 ft.) high, at Schwaz, Tyrol. The Municipal Hall at Vienna (*Figs.* 5 and 6) can accommodate 25,000 spectators. There are two stands each 100 m. (328 ft.) long by 20 m. (66 ft.) high ; one is 30 m. (99 ft.) wide and the other 40 m. (131 ft.). The roofs cover 100 m. (328 ft.) square, and there are no intermediate supports ; they are carried on frames with horizontal ties hinged at the ends. Each of the two ties has a tensile strength of 375 tons, and is reinforced with 64 Torstahl 80 bars of 12 mm. (0·475 in.) diameter. The steps were precast on the site. In these structures the following grades of Torstahl were used : *Figs.* 1, 2, and 3, No. 40 ; *Figs.* 4 and 5, No. 60.

Fig. 6.—Municipal Hall, Vienna, during Construction.

An Early Grain Silo in England.



Grain Silos at Silvertown, London. Built in 1909.

[Eight silos each 80 ft. high by 20 ft. diameter. Founded on 124 piles 14 in. square and up to 35 ft. long. Walls 6 in. thick.]

DENMARK

By NIELS MUNK PLUM

DIRECTOR, DANISH NATIONAL INSTITUTE OF BUILDING RESEARCH.

Introduction.

WHEN we try to picture a long period of development the background is distant, relatively unknown, and hazy, and we never fail to get an impression that very much has been achieved during the period. If, however, we try to see the period from the level of the knowledge and skill that existed at its beginning, the view may be clearer because the differences between now and then become less pronounced. To get a fair view of the period it must be looked at from both ends. The backward look is easy, but it may be deceptive. Our system of education and the newspapers often praise new developments in such an extravagant manner

Fig. 1.—Reinforced Concrete Bridge built in Copenhagen in 1894.

that few will hesitate to judge the last fifty years as a period of vast improvement. To maintain a sound balance I have therefore, as far as possible, tried to judge the period by a forward look from 1905. Born in 1911 and graduating in civil engineering in 1934, this has not been easy, but as a result of studying a vast number of old technical periodicals and papers I hope that I can visualise the early years of the century as objectively as an older man, because memory is very imperfect and often deceives. In this connection one must thank the technical periodicals, and among them "Concrete and Constructional Engineering", for making this possible.

Documentation.

In 1905 only five periodicals of importance concerned wholly or partly with one or more of the many aspects of concrete were issued in Scandinavia, and by 1955 the number had grown to twenty-one. A bibliography of their contents has just been issued by the Danish Institution of Civil Engineers, and from this it has been possible to prepare *Fig.* 2.

The articles printed in these journals are divided into the following nine

groups used in the universal decimal classification system: Group 620, Testing of materials; 624, Civil engineering; 625, Road and railway engineering; 627, Harbour and waterworks; 629, Transport engineering; 666·9, Cement and concrete industry; 666·94, Cement manufacture; 666·977, Precast concrete; 690, Building (methods and design); 691, Building (materials and components); 693, Building construction (execution of work).

The number of articles published in Scandinavian journals in each five-years' period from 1900 to 1954 is given in *Table* 1. It is seen that while the number

TABLE 1.

Five years ending	1904	1909	1914	1919	1924	1929	1934	1939	1944	1949	1954
Number of articles	54	103	137	210	175	265	289	378	418	626	803

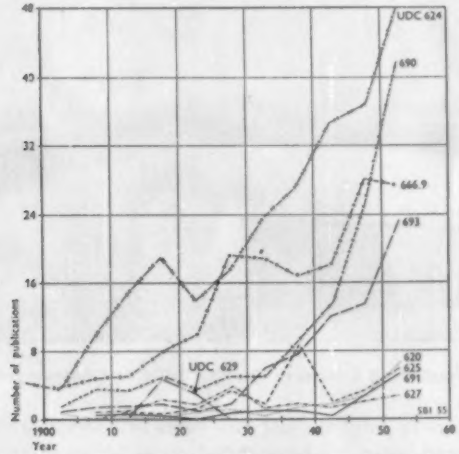


Fig. 2.—Articles published in Scandinavia, 1900–1955.

of periodicals increased about four times from 1900 to 1954, the number of articles contained in them increased about sixteen times; this is an average annual growth of 5·7 per cent., which corresponds favourably with the other developments mentioned later. Apart from the interruption of the two world wars and the depression in the early 1930's, which are apparent in all the curves, other characteristic trends are visible which will be commented upon later.

Concrete Construction.

Danish civil engineers and contractors followed with great interest the rapid development of reinforced concrete on the Continent since Hennebique and Coignét in France in 1892 got their first patents for reinforced concrete, and in 1894 the first reinforced concrete bridge in Denmark (*Fig.* 1), designed by Professor A. Ostenfeld, was constructed by the contractors Schiøller & Rothe. This bridge

is still in use. It is about 22 m. (73 ft.) long and 6 m. (20 ft.) wide, and designed for a live load of 500 kg. per square metre (100 lb. per square foot).

In the years immediately following, the use of reinforced concrete spread rapidly and new contracting firms specialising in concrete and reinforced concrete were founded. The most important of these was Christiani & Nielsen, which was founded in 1904, and by 1907 had an annual turnover of about 1,000,000 kr. (about £50,000). The writer worked with this company from 1935 to 1947 and would particularly mention one of the co-founders, Mr. Aage Nielsen, who was a technically and practically gifted contractor with the intuition that brings the explorer safely through a jungle of new and unsolved problems. His presence was an inspiration to every employee, from responsible engineers to labourers on the site, and it is mainly due to him that the company, and later many other contracting companies started by engineers who had been trained by this firm, met with success throughout the world.

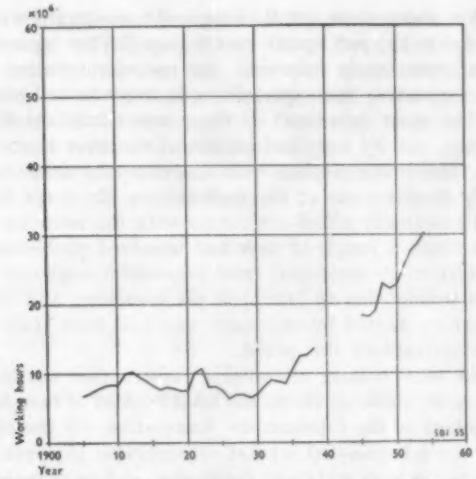
An idea of the total volume of concrete construction can be obtained from the curves in *Fig.* 3, in which (*a*) shows the total number of man-hours worked by employees of members of the Contractors' Association, (*b*) the cement produced per year, and (*c*) the accumulated cement consumption per year. These curves show declines due to the wars and trade depression, and an average annual growth of 3½ per cent. and 4½ per cent. respectively. Considering the increase in mechanisation during the period, the figures are a reasonable guide to the increase in structural and civil engineering. It is of interest to compare these percentages with the growth of 5·7 per cent. in the number of technical papers and articles published, as this illustrates the importance of the technical periodicals and contradicts the view that engineers are reluctant to pass on the results of their experience to others.

During the early years attention was concentrated on new methods of design and construction. There were early wage disputes, and in 1907 a section of the Contractors' Association was formed, comprising contractors who specialised in concrete, to negotiate with the Concrete Labourers' Union; an agreement was reached that ensured an average hourly wage of 40 to 45 Danish øre (5*d.* to 6*d.*) per hour. This agreement permitted piece-work, which had previously been considered to be inconsistent with good workmanship. The piece-rate system has proved very useful to contractors in preparing estimates, and the savings so obtained are generally believed to outweigh the difficulties of applying piece-work rates to new materials and equipment. In Denmark to-day from 50 to 60 per cent. of concrete work is paid for by piece-rates in the metropolitan districts and 30 to 40 per cent. elsewhere.

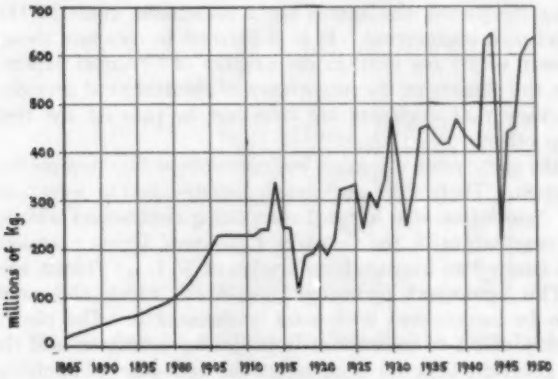
Some Early Structures in Denmark.

As already mentioned, in 1894 the first bridge (*Fig.* 1) was built. A second bridge (*Fig.* 4) was built in 1906 by Christiani & Nielsen, and this also is still in service. In the same year this firm designed and constructed two quay walls of the type shown in *Fig.* 6; this design, which originated in Denmark, is now used the world over.

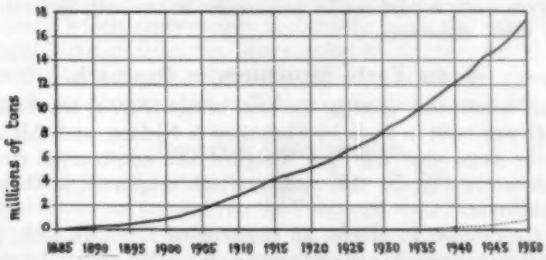
In 1905 Captain N. F. Møehl, an engineer of Danalith Ltd., patented the precast tee-beams shown in *Fig.* 5, and these were used in 1907. In 1910 a concrete chimney was cast in sliding forms, also developed by Captain Møehl. A cross



(*a*) Labour Employed on Concrete Work, 1906–1955, in Millions of Man-hours.



(*b*) Annual Cement Consumption, 1885–1950.



(*c*) Cumulative Cement Consumption, 1885–1950.

Fig. 3.

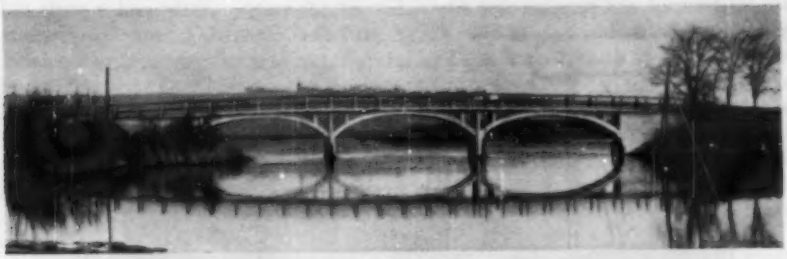


Fig. 4.—Road Bridge at Randers. Built in 1906.

section of the bottom (*Fig.* 7) consists of three identical circular rings drawn apart to form a clover-leaf. At the top of the cone-shaped chimney the three rings come together to form a circular cross section. Chimneys of this type, though slightly modified, are still being constructed as is seen in *Fig.* 8, which shows a chimney built by Danalith Ltd., for the National Portland Cement Co., Pty., Ltd., in Cape Town in 1939.

Many bridges have been built, especially of the bow-string type, and these illustrate the progress in design and in the quality of concrete. Compare, for example, *Fig.* 9, a bridge with a span of 54 ft. built in Germany in 1910 by Danish contractors, with the bridge with spans of 265 ft. built in Sweden by Danish contractors in 1934 shown in *Fig.* 10. Two bridges, with lengths of 1178 m. (3600 ft.) and 3211 m. (9600 ft.) respectively, were built in the early 1930's across the Lillebelt (*Figs.* 11, 12 and 13) and the Storstrøm (*Fig.* 14). The concrete foundations and approach spans of both these bridges presented new and interesting problems which were skilfully solved by the contractors, Monberg & Thorsen and Christiani & Nielsen. The steel superstructure of the Lillebelt bridge was built by Gruen & Bilfinger, Krupp, and Eilers, of Germany, and the steel superstructure of the Storstrøm bridge by Dorman Long & Co., Ltd., of England.

During the first world war the construction of concrete vessels aroused considerable interest everywhere, but it was relatively short lived. A ship of 1800 tons deadweight built for the Danish merchant navy behaved well at sea, was easy and cheap to repair, and remained in service for several years (*Figs.* 15 and 16).

In 1929 concrete and reinforced concrete were at last allowed for the construction of houses and dwellings and here, as elsewhere, a tremendous development

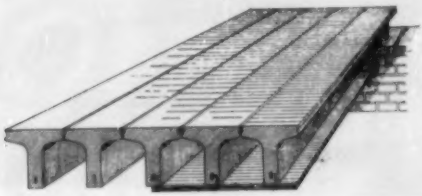


Fig. 5.—Precast Floor Beams used in 1906.

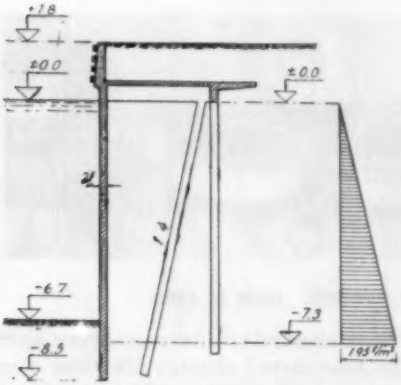


Fig. 6.—Cross Section of Quay Wall at Assens, built in 1906.

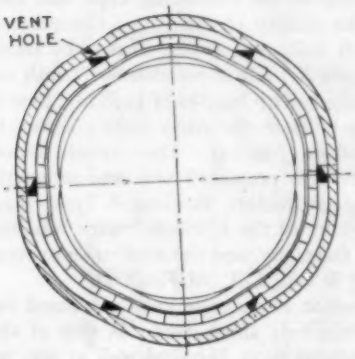


Fig. 7.—Cross Section of Bottom of Chimney. Built in 1910.

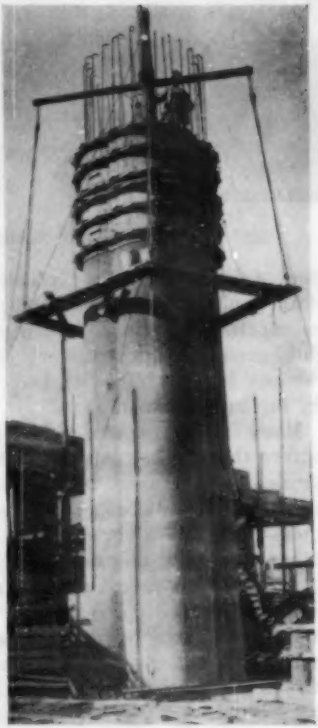


Fig. 8.—Chimney built in Cape Town in 1939.

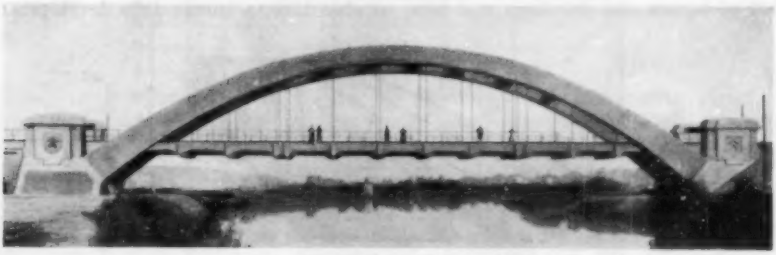


Fig. 9.—Railway Bridge, Thuringen, Germany. Built in 1910.

has since taken place. After the second world war interest has focused on pre-stressed and precast elements, and *Figs.* 17, 18, and 19 give an idea of the development. *Fig.* 17 shows a military hospital at Copenhagen, with precast columns, built in 1953 by Messrs. Larsen & Nielsen. *Fig.* 18 is a block of flats fifteen stories high built in Copenhagen by the same firm, who also built the factory with precast columns and beams shown in *Fig.* 19. The load-carrying structure is normally of ordinary concrete, whereas generally the walls are of cavity or light-weight concrete blocks with a density of 40 lb. to 50 lb. per cubic foot. In the

Fig. 10.—Road Bridge at Hammar, Sweden. Built in 1910.

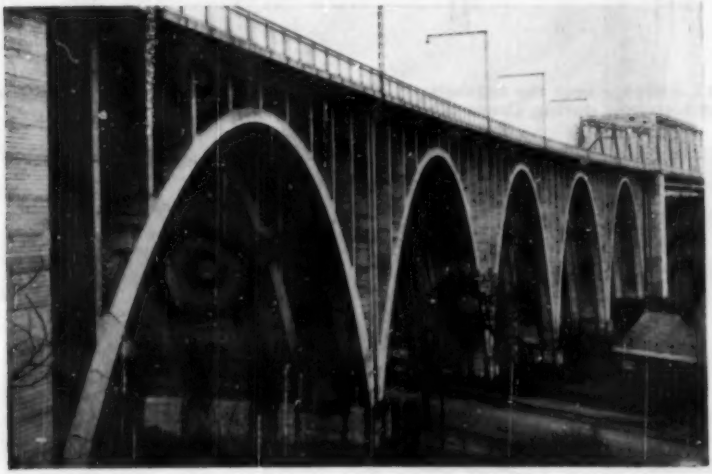


Fig. 11.—The Approach to the Bridge over the Lillebelt.

construction of the walls (whether load-bearing or not) of houses, lightweight blocks and slabs, which are now being precast the full story height, have largely displaced clay bricks.

Just before the second world war much interest was taken in concrete roads,

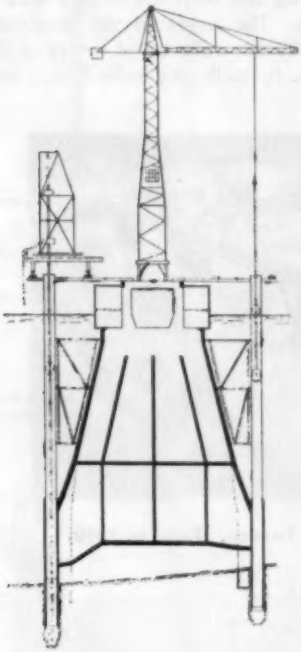


Fig. 12.—Bridge over the Lillebelt: Pier at Mid-stream during Construction.

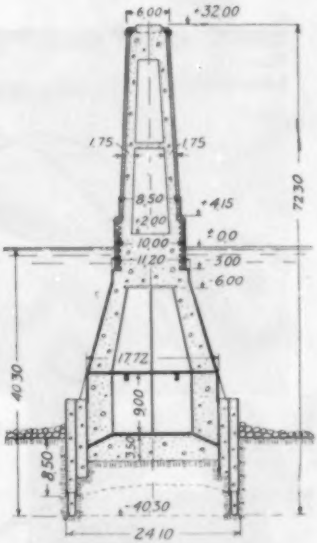


Fig. 13.—Bridge over the Lillebelt: Cross Section of Pier.

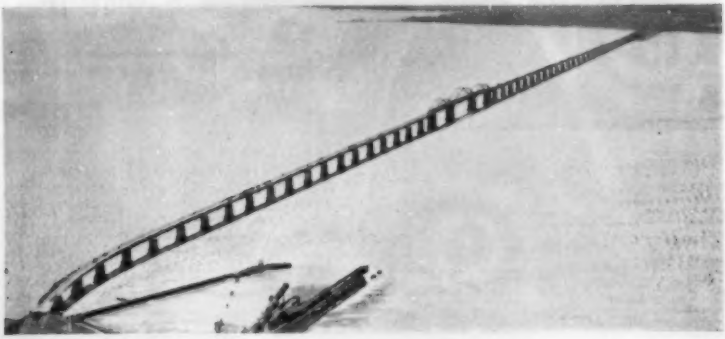


Fig. 14.—Storstrøm Bridge.

but restrictions on the use of cement have only very slowly allowed concrete roads to be built again after the war.

Danish Work Abroad.

Engineering skill and contracting experience are very suitable for export, and Danish civil engineers and contractors were quick to seize the chance. Before the first world war companies affiliated to Danish concerns were established in ten countries, and during the past fifty years work has been done in about fifty countries. The international character of Danish civil engineering may be seen from *Fig.* 20, which shows that about half of the Danish civil engineering graduates in the period 1905 to 1942 worked or studied more than one month

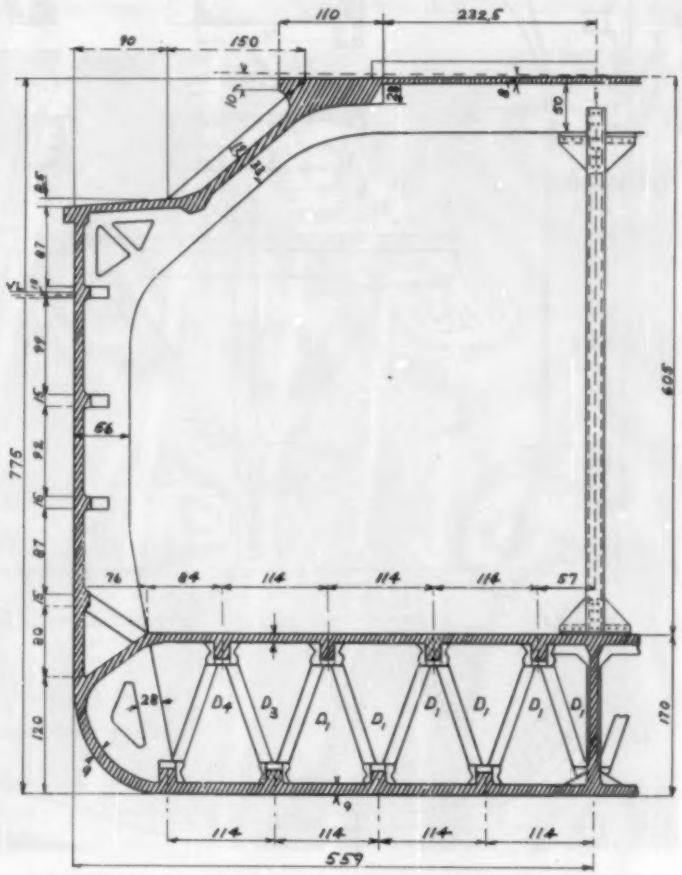


Fig. 15.—Cross Section at Midship of Concrete Ship.

abroad ; the figures do not include civil engineers who died before 1929. Unfortunately the collection of this information was discontinued in 1942 and has not yet been completed, but the writer believes that the proportion is steadily increasing. Precise information is not available of the amount of work done by Danish contractors abroad, but it is likely that Danish firms have built abroad about 7000 structures at a cost of about 5 billion kroner (£250,000,000) ; to-day the rate is about £20,000,000 a year. Some photographs of recent works are shown in *Figs.* 21, 22, and 23. *Fig.* 21 shows a bridge at Lisbon built in 1950 by

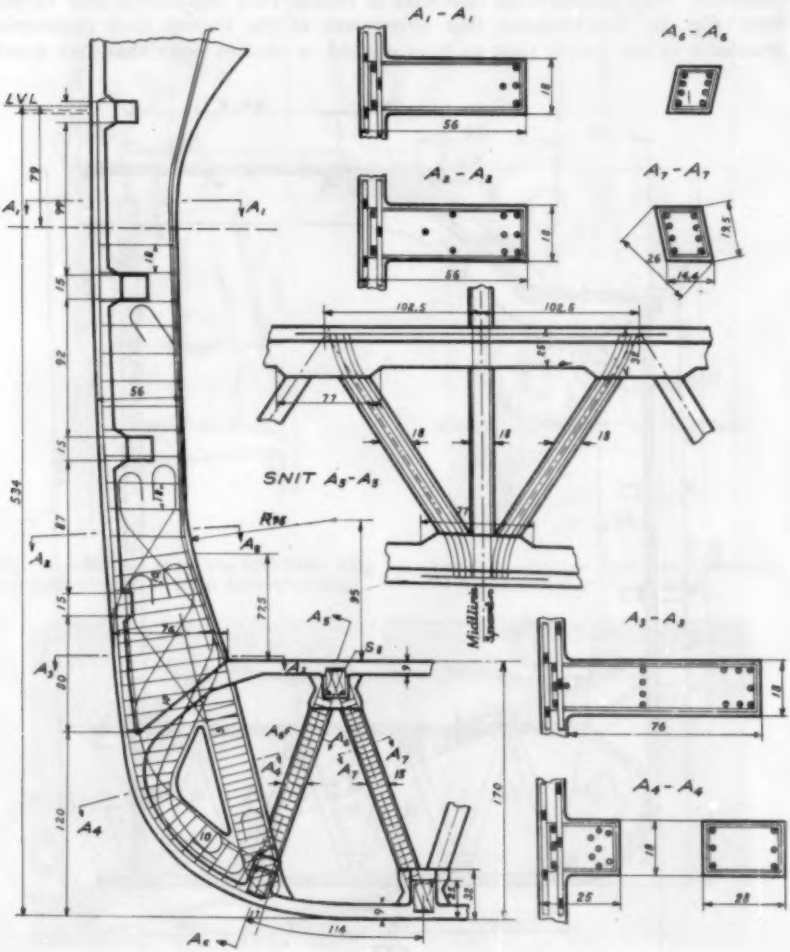


Fig. 16.—Details of Reinforced Concrete Ship.

Messrs. Højgaard & Schultz ; *Fig.* 22 is a grain silo built by Kampsax at Teheran ; *Fig.* 23 is the Owen Falls dam in Uganda built in 1953 by Messrs. Christiani & Nielsen.

Durability of Concrete.

From 1900 to 1905 Danish engineers were confident of reinforced concrete as the result of tests already made in other countries. The early advocates of the new material emphasised the importance of its resistance to fire and to decay, as well as the saving in construction time and the decrease in the dead load compared with other permanent building materials. To-day the picture has changed. Fire resistance and resistance to decay are accepted as facts. With regard to savings in construction time the picture is even reversed, for nowadays concrete cast in place may be considered a relatively slow process compared with prefabricated construction. Also the higher strength of the concrete made to-day

Fig. 17.—Military Hospital, Copenhagen. The Columns were Precast.

and the slender members now used make many of the early concrete structures appear rather clumsy. Engineers and contractors of fifty years ago were extremely optimistic about the future of concrete, and their expectations have in some respects been fulfilled. Concrete and reinforced concrete have been put to more uses than could possibly have been foreseen, and if no new and revolutionary materials appear this development will continue.

It is surprising how little attention was given to the durability of concrete in the early period. Because concrete is composed mainly of natural stone and has a strength almost equal to that of natural stone, it is not difficult to understand why its durability was not doubted. The engineers of those days would, however, have been very surprised had they known how some of their structures would deteriorate. Apart from the reasons that led them to believe that concrete would last for ever, it is not difficult to understand why durability in general has become a problem only recently. *Fig. 3c* gives an approximate idea of the total amount of cement used in plain and reinforced concrete structures. The area under the curve is proportional to the accumulated total, and in general has the

Fig. 18.—Fifteen-story Block of Flats at Copenhagen, built with Sliding Shutters.

same shape as the other curves in *Fig.* 3 and shows an annual increase in the yearly volume of about 6 per cent. If the time that elapses without serious and visible deterioration of normal concrete under average exposure is assumed to be, for example, 20, 30, 40, 50, and 60 years, the percentages of damaged structures at various times can be calculated as in *Table* 2. From the table it is obvious that, if the durability of concrete is, for example, fifty years, failures would not become a serious problem until after that period, and in 1955 only about 8 per cent. of the structures built in 1905 would be more or less damaged. This corresponds rather well with experience in practice, and indicates that a life of about fifty years is reasonable for structures built early in this century; the last two

Fig. 19.—Factory with Precast Columns and Prestressed Beams.

lines of the table suggest that the problem will be very serious indeed as more of these early structures reach the age of fifty years.

TABLE 2.—PERCENTAGE OF DETERIORATED STRUCTURES.

	Period before deterioration takes place (years).				
Year.	20	30	40	50	60
1925	26	9	0	0	0
1930	36	12	2	0	0
1935	41	18	5	0	0
1940	44	24	12	1	0
1945	49	28	12	3	0
1950	46	30	17	6	1
1955	46	31	19	8	2
1960	46	31	20	11	4
1965	46	31	20	12	5

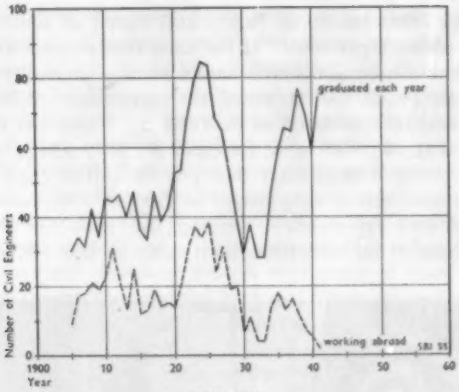


Fig. 20.

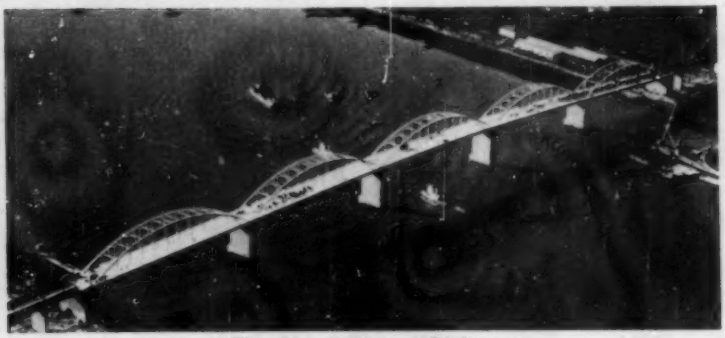


Fig. 21.—Bridge at Lisbon.

Fig. 22.—Grain Silo at Teheran, Iran.

It is a matter of economics whether it is better to build concrete structures that have a comparativcly short life or to improve the concrete. Much research is now devoted to improving quality, but our predecessors cannot be blamed for leaving the problem unsolved, because the relative values of the life of a building and the cost of better concrete could not be assessed without the practical experience of recent years as expressed, for example, in *Table* 2.

Research.

As mentioned earlier, research on concrete is as old as concrete itself, and besides the professional curiosity in the early days of reinforced concrete it was no doubt necessary to have some research data to persuade more conservative clients and authorities to use the new material. In Denmark official research on cement began with the creation of the State Testing Laboratory at the Danish Technical University in 1896 under the auspices of the Institution of Danish Civil Engineers, which was founded in 1892. The work in this laboratory increased steadily, and in 1909 it came under the ægis of the Ministry of Commerce. At present the Laboratory has an average annual budget of 800,000 kr. (£40,000), most of which is paid by industry for routine testing, among which cement and concrete play an important part.

More research was begun in 1904 when E. Suenson, after two years' study of new materials in other countries, was charged by the Danish Technical University with the creation of a new laboratory for testing building materials. Suenson early concentrated most of his interest on concrete and, by his brilliant laboratory work and the gifted presentation of his findings, did more to forward concrete than anyone else in Denmark. In 1916 Suenson was appointed Professor at the University, and from then until 1948, when he retired, devoted his time to research and the education of a whole generation of Danish civil engineers. Suenson's work won high international reputation, and he has continuously produced books and papers since, in 1907, he published his first textbook on reinforced concrete.

Almost since its establishment in 1882 the F. L. Smidth Co. has undertaken research on cement, but most of their findings were, especially in the earlier years, for commercial reasons kept secret. Such secrecy appears to the writer to be a short-sighted policy, and it is noted with satisfaction that in 1934 the Technical Information Bureau of the Danish cement industry was created. This bureau has for twenty years actively disseminated information and the results of research on improving concrete by giving free advice on problems relating to concrete and by issuing a quarterly bulletin " Concrete Technique ".

About 1885 the consumption of cement in Denmark was negligible. In 1896 production was 35,000 tons, in 1914 about 180,000 tons, and in 1955 about 800,000 tons. From *Fig.* 3(*c*) it can be calculated that the average annual increase in the consumption of cement has been about 4½ per cent. As the average annual increase of the rate of building has been about 3½ per cent., and the strength of concrete during the period has increased from about 200 to 550 kg. per square centimetre (2800 to 7700 lb. per square inch), or about 2½ per cent. per year, it is obvious that concrete has been used to a relatively greater extent, no doubt at the cost of other building materials.

The Danish Institution of Civil Engineers has initiated and sponsored research

and investigations, especially those required in the preparation of standards. The first standards for concrete and reinforced concrete were issued in 1908. They have since been revised five times, and the current standards DS411 were issued in 1940. In 1946/7, on the suggestion of Mr. Søren Rasmussen, consulting engineer, and the writer, more intensive work was started, and the Concrete Section now issues the periodical "Beton & Jernbeton" and pamphlets and books, and arranges classes for engineers, site superintendents, and others.

Some of the activities of the Concrete Section, especially on research, were, however, taken over by the Danish National Institute of Building Research, which was founded in 1947 and has an annual budget of 2,500,000 kr. (£125,000). The importance placed by the Institute on research is seen from the fact that slightly more than a quarter of the hundred or so publications issued so far by the Institute deal with concrete, reinforcement, or shuttering. Many of these publications are in the English language or have extensive summaries in English. In some circles there seems to be an impression that too much research is being done on concrete and reinforced concrete. The curve 666·9 of *Fig.* 2 referring to cement and concrete shows, however, that this is apparently not so. In the 1920's the subject attracted much attention, and a closer study of the curve shows that one-third of these papers dealt with the improvement of concrete, another third with the proportioning and production of concrete, and the other third with lightweight concrete, other special concretes, and precast concrete. The average annual increase in the number of papers in this group from 1900 to 1929 is as high as 6½ per cent. Apparently the depression of the early 1930's affected the interest in these subjects, and interest was not resumed until the years immediately after the second world war. The interest this time was again surprisingly concentrated and short, and was followed by a decline during the last five years, which is in great contrast to the rapidly-increasing interest in all other subjects. The average annual increase in the number of papers between 1900 and 1955 was only 4 per cent.

The conclusions that can be drawn from the curves in *Fig.* 2 are limited, and the ratio between the amount of research and the number of publications in the different categories is not known. It may, however, be concluded that those who think that too much research is being done on concrete should base their opinion on conditions five to ten years ago. The relatively decreasing trend in the publication of articles on concrete in Scandinavia in recent years is, however, noteworthy, and if the tendency is continued an investigation should be made to see if additions are necessary to our present research.

During recent years we have, as have others, concentrated particularly on the durability of concrete, and Denmark is one of the few countries in Europe where much deterioration can be definitely traced to cement-alkali reactions. A considerable sum has recently been appropriated to a special research group under the auspices of the Danish National Institute of Building Research and the Danish Academy of Technical Sciences jointly to study the question, and it is hoped soon to determine the sites of these aggregates and the extent of the danger. Work has also been started, in collaboration with the Technical University, to develop methods of neutralising reactive aggregates, and we are further in close contact with the research that is going on at the Building Research Station in England on this question.

The Future of Concrete.

In evaluating the development described in the foregoing it is tempting to use superlatives to describe the increase in size and numbers of concrete structures. Quantitatively the development has been impressive, and I would emphasise that the figures are given in terms of the use of concrete and are not influenced by the inflation of money values. It is, however, an open question whether much improvement in quality has taken place during the period 1905 to 1955. It seems to me that the answer is almost in the negative, for the following reasons. First, nearly all the principal inventions were made before 1900, and the developments since have been refinements and improvements only of these principles. Secondly, no radical change has taken place in the quality of concrete. In spite of the increase in the strengths of cement and concrete, we have not yet produced a material as strong and durable as hard natural rock. Experience during the period has, on the contrary, made us more doubtful than our predecessors about the possibility of doing so.

So far as the writer can see, much of the present research therefore takes the form of improving a partly obsolete material and partly obsolete methods, and I believe that, if very basic and radical changes in the quality of cement and concrete are not soon made, the next fifty years may see the eclipse of concrete and reinforced concrete by new materials. Concrete as it is now known is not

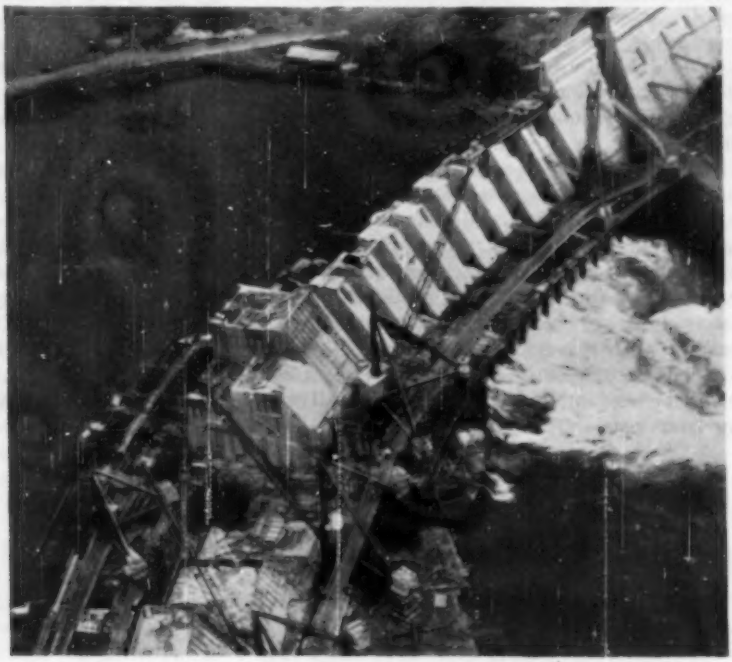


Fig. 23.—Dam at Owen Falls, Uganda.

light enough or cheap enough for many semi-permanent constructions, nor durable enough for really permanent structures, and unless it can be made either much cheaper or much better it will be in serious competition with cheaper or more durable materials.

In studying the literature of the last half-century it is surprising to see how many of our current problems were present in 1905 to 1910, and to see that our knowledge has so little improved during the period. It seems common nowadays, especially in larger countries, to approach the problems of research by making extensive and expensive tests with perhaps little previous thought and statistical planning. The result is dismaying. Tremendous amounts of test data are accumulating which may give some immediate help in practice but which cannot be scientifically explained, and these primitive results are often reached at a cost many times more than the cost of well-planned research where testing is only the least part of the project. Thanks to the concrete periodicals, which give a very close picture of the history of concrete and the mistakes that have been made, the writer is able to conclude with some suggestions for the future of concrete research. Before entering on a new project, practice, or research, much time and money will nearly always be saved if the following suggestions are adopted.

(1) Read the literature—it will save repeating previous mistakes, and enable a much more accurate aiming at the target. It is quite fantastic to see the amount of repetition of the same tests that has taken place because of an ignorance of what has been already done.

(2) Think before starting actual experiments. From existing knowledge, it is frequently possible, by calculation of the physical and chemical processes, to reach the goal without tests, or to get so near to the truth that tests are needed merely to verify or to state arithmetically what is conceived by the mind.

(3) If and when tests are necessary, simulate the actual conditions of exposure in practice as closely as possible, even if this entails considerable complications, and record as many test conditions and test results as possible. The number of accelerated standard test procedures that are poorly correlated with actual conditions in practice is overwhelming, and presents a problem of high importance to national economy. Economic conditions must mainly be based on the degree of safety under service conditions, but at present this degree of safety has little connection with the results of accelerated tests. Further, a valuation of test results will be frequently complicated by lack of data which at the outset are considered irrelevant, and some extra data will often, when kept on record, render many later tests superfluous.

FINLAND

By BEATO KELOPUU

DIRECTOR OF BUILDING DEPARTMENT, FINNISH STATE BOARD OF BUILDING.

OF the various structural materials, it can be stated that beyond doubt concrete, plain or reinforced, cast in place or precast, is the material most favoured by architects, engineers, and contractors in Finland, particularly for structures in which all the technical and economic advantages of concrete can be fully utilised.

Cement was first used in Finland in the early 1850's, and the first small cement factory was built near Helsinki in 1869. However, the industry really started with the erection of factories at Pargas in 1914 and Virkby in 1919. These factories, together with the latest works at Ihalainen, have been expanded and modernised to meet the growing demand until to-day Finland is independent of imported Portland cement; the yearly production in 1954 was 1,039,000 tons, and only special cements, such as high-alumina and white, are imported.

The first reinforced concrete structures in Finland were built in 1904. By 1920 this material was commonly used for floors in dwellings, and in the 1930's concrete was used for the floors of most new buildings. The early floors were a composite construction of steel joists and concrete. These were followed by inverted reinforced concrete T beams, which in turn, in the late 1930's, gave way to slab floors with beams between the columns only. The change resulted in large savings in shuttering, materials, and especially in labour. The use of wood may not seem of great importance in a wood-producing country like Finland, but in fact the contrary is true. Wood is Finland's most important export, and every effort has to be made to export as much as possible. Particularly since the war, the need to save wood has been the first principle in the design and construction of concrete structures.

Other factors governing development have been the sudden expansion of the building industry since the war to meet the scarcity of housing that still persists to-day, and the expansion of industries in general to meet the large war reparations that Finland had to pay to Russia. These demands created new problems for the concrete engineer, and necessitated an increase in production that was possible only by working all the year round, even through the severe winter. Apart from the need for production, work throughout the year is also of considerable social importance, especially in the northern districts where seasonal variations in the demand for building labour have always been a problem. In Finland this social aspect, together with the need to increase production, has encouraged the carrying out of construction in the winter. The most important results of the need for greater production in building are the increased use of prefabricated structures and mechanisation.

Prefabrication.

The first reason for using precast concrete was the saving in wood, but there were other advantages such as increasing the possibility of winter construction, saving labour and material, and, in the form of exposed concrete, making possible a new architecture. In Finland prefabrication is applied mainly to industrial buildings, but attempts have been made to develop prefabrication methods for houses, as is mentioned later.

Fig. 1.—Precasting during Winter.

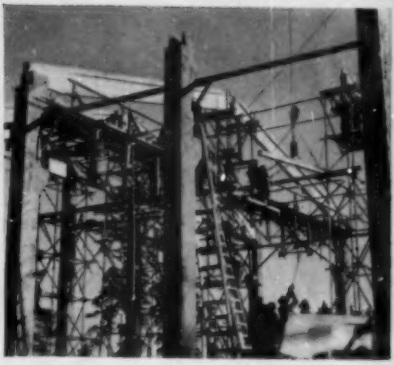


Fig. 2.—Assembling a Tie-Beam.

Fig. 3.—Municipal Tramway Depot, Helsinki.

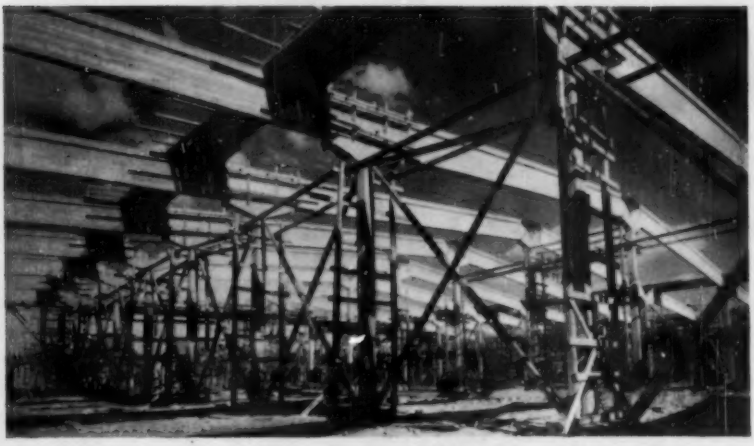


Fig. 4.—Erection of Columns and Beams, Tramway Depot, Helsinki.

Most precast concrete is made on the site of the structure. Lack of equipment for hoisting heavy loads limits the weight of the precast elements and is the main reason why the parts are often cast as near as possible to their place of use. *Fig.* 1 shows the casting of the columns and beams for a pulp factory. The work was done in the winter, light movable plywood covers and steam heating being used to protect the " fresh " concrete against the frost. The structure is a 3-hinged frame with a span of 75 ft. 6 in. and the members are prestressed ; a prestressed tie-beam being formed of smaller parts is seen in *Fig.* 2.

The columns and beams of the municipal tramway depot at Helsinki (*Fig.* 3) were cast in the summer ; *Fig.* 4 shows the building during erection. A multiple-story building for the University of Helsinki, with prestressed precast beams and factory-made prestressed ribbed slabs, made by the pre-tensioning process, is shown in *Fig.* 5. When precast members would be too heavy for the hoisting plant available, they are assembled of smaller parts by means of prestressing. The

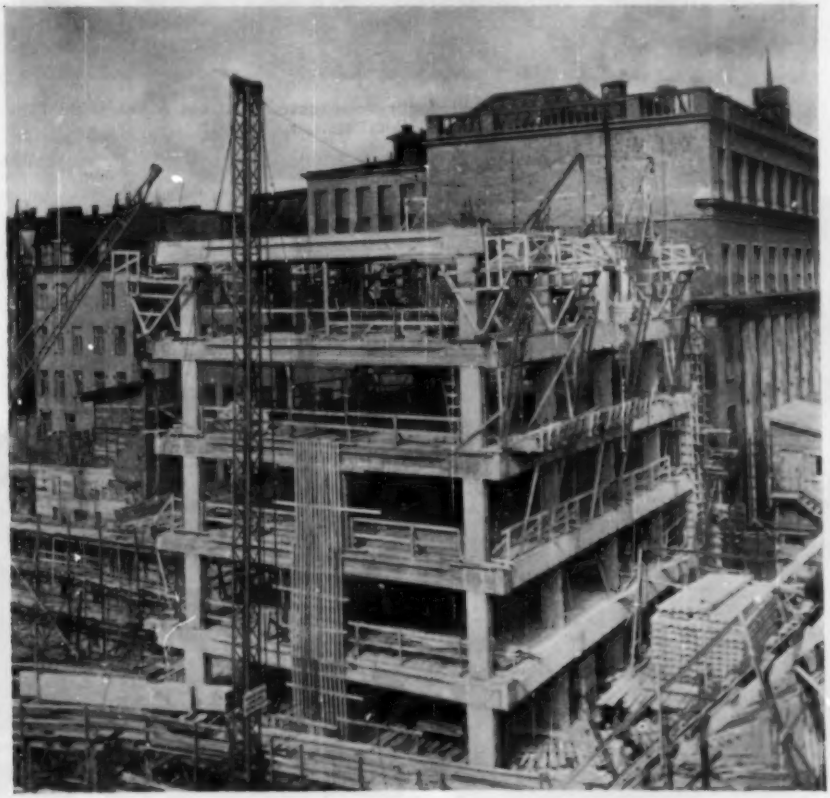


Fig. 5.—Building Constructed with Prestressed Precast Beams and Slabs.

Fig. 6.—Hangar at Helsinki Airport: Prestressed Trusses Made with Precast Sections.

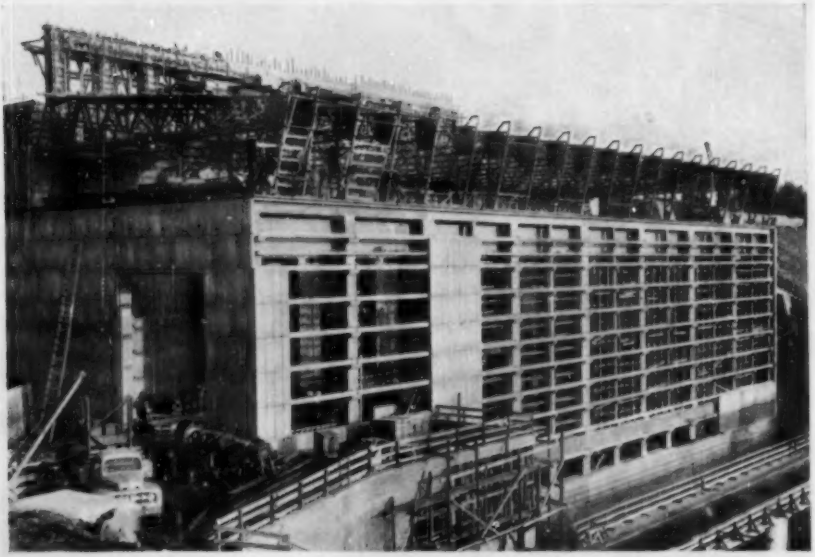


Fig. 7.—Hydroelectric Power Station Faced with Concrete Slabs.

hangar at Helsinki Airport (*Fig.* 6) is a good example of this method ; the trussed secondary beams seen in the photograph have a span of 150 ft. and are spaced at 37 ft. 2 in. centres ; each beam comprises thirty-three units.

Although most precast work is at present done on the site, there is a growing tendency for such members to be made in factories, especially lighter parts and parts demanding great accuracy and smooth surfaces, such as facing slabs. *Fig.* 7 shows a hydroelectric power station in north Finland, and *Fig.* 8 the Palace Hotel in Helsinki built for the Olympic Games of 1952 ; both these structures are faced with concrete slabs.

Methods of Construction.

The second main development has been in mechanisation, and this has greatly influenced design. As most residential buildings are still concreted in situ, the development of this class of building provides a good example of this tendency in design. Multiple-story dwellings formerly had load-bearing brick walls, but the brickwork interfered with the concreting and, particularly in the winter when fresh concrete had to be protected against frost, this was a great disadvantage. This resulted in the use of reinforced concrete " skeleton frame " or " box-frame " construction and the brickwork is carried out later, or replaced by precast concrete wall panels. This method is very popular because it reduces the plastering work, which is always a bottleneck. But even this development did not satisfy the need to shorten the building period.

Fig. 8.—Palace Hotel, Helsinki.

Fig. 9.—Winter Construction with Sliding Forms.

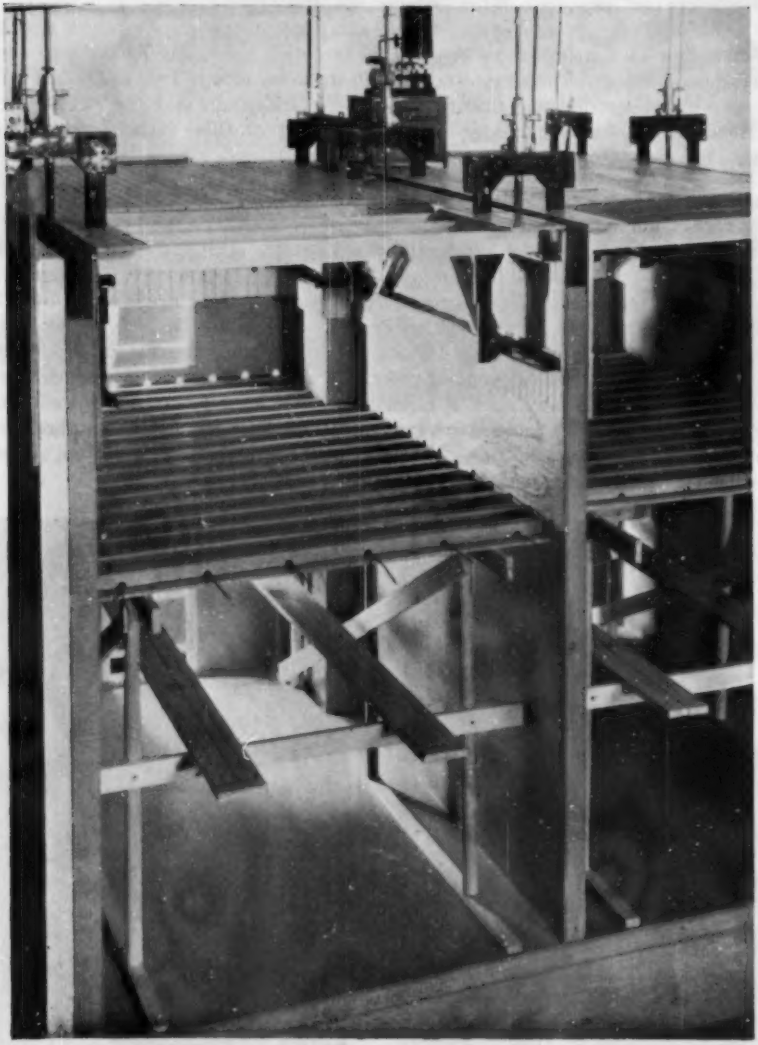


Fig. 10.—Model Showing Method of Moving Form Construction.

The slip-form construction method, formerly used only for silos and similar buildings, made great progress when the Swedish method using hydraulic jacks was introduced, and hand-jacking was outmoded. With this method it is possible to construct reinforced concrete walls with a lining of lightweight blocks to provide insulation at the rate of a story a day, the lightweight blocks being put in the form during concreting. The method may be used in the winter if the interior of the building is temporarily heated and the wall openings closed (*Fig.* 9). This method has one great disadvantage. It was impossible with the construction methods in common use to complete the floors at the same pace as the walls. The floors had to be constructed afterwards, causing delay and difficulties with construction joints, especially when projecting reinforcement was used to achieve a monolithic structure. The floors could, however, be built under shelter in the

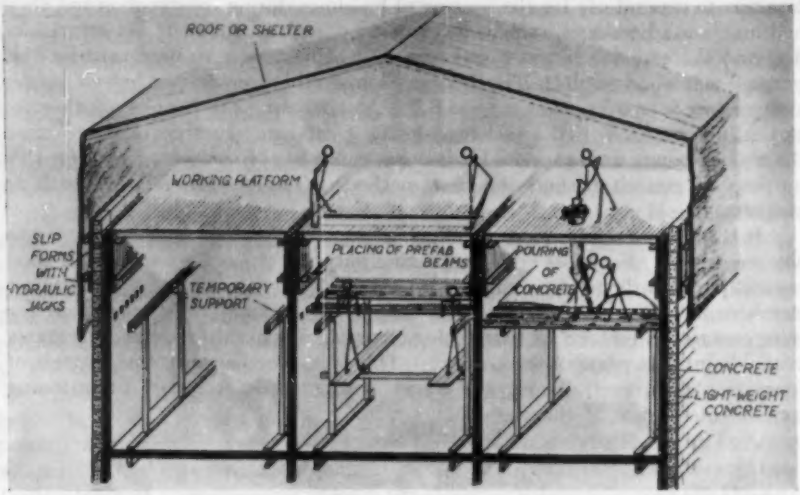


Fig. 11.—Winter Construction Using Moving Forms and Composite Floors.

winter. A new method (*Figs.* 10 and 11) has therefore been devised. Very light precast floor beams, comprising the principal reinforcement and acting as shuttering for concrete cast in place to form a composite slab, are used, and the secondary reinforcement is placed in the topping. This method has proved very satisfactory, and it is now possible to complete a story in one day including floors.

Concreting in Cold Weather.

To-day concrete work is carried out even in Lapland, north of the Arctic Circle, during the winter. The main precautions are the heating of all the materials, efficient placing and compaction of the concrete, immediate covering of the concrete to avoid loss of heat, and heating of the stories beneath the freshly-placed concrete until it is frost-resistant and sufficiently strong. All this requires careful planning before starting the work.

The batching and mixing plant is generally sheltered and heated with steam,

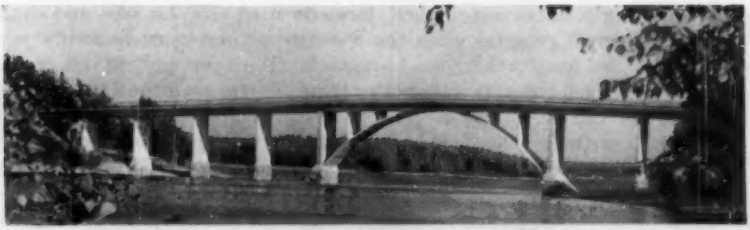


Fig. 12.—Käkisalmi Bridge. Main Span 132 ft. 8 in.

and steam is also used for heating the materials. For covering, straw mats appear to be the most suitable material. Coke braziers and stoves burning wood were formerly in general use for the heating of buildings during construction but they had many disadvantages, such as low efficiency, high labour costs, serious risk of fire, and the emission of gases and smoke. Oil heaters have been used for this purpose with good results. The modern Finnish oil heaters have a hot-air blower and produce 80,000 kg./cal. (317,000 B.T.U.'s) per hour. The heaters are thermostatically controlled. To avoid heat losses great care must be taken to close the wall openings, and a special bituminous paper has proved very useful for this purpose. Research to find the best methods of winter concreting is still in progress.

It is not only in housing and industrial construction that reinforced concrete has progressed. For most civil engineering purposes it has been used with good results, particularly for very many highway bridges (*Figs.* 12 and 13). Precast members have not yet been used for bridges in Finland. The conditions for using concrete in Finland are extremely favourable due to the first-class aggregates available in most parts of the country. This fact, together with the progress of concrete construction all over the world, will certainly result in a continuing increase in the use of this material.

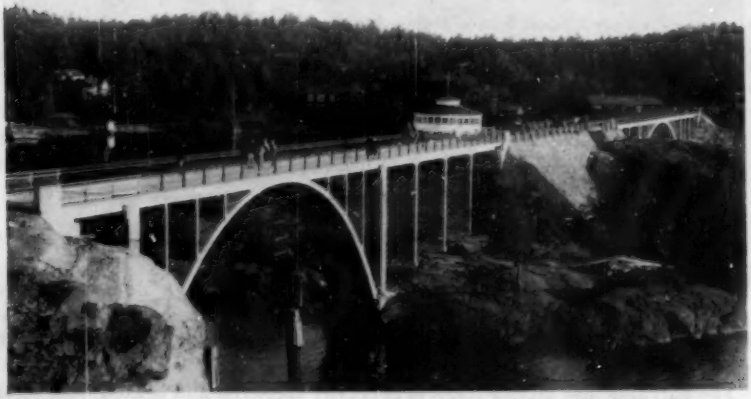


Fig. 13.—Naantali Bridge. Main Spans 148 ft. 4 in. and 98 ft. 2 in.

U.S.S.R.

By V. TURKIN

DIRECTOR OF THE CENTRAL RESEARCH INSTITUTE OF INDUSTRIAL CONSTRUCTION, MOSCOW.

Early Development.

DURING the past half-century concrete and reinforced concrete have been increasingly used in the U.S.S.R. in preference to other materials for all types of construction. Concrete and reinforced concrete were already being used in Russia at the beginning of the present century ; for example, in 1904 a reinforced concrete lighthouse 118 ft. high was built at Nikolayev on the Black Sea.

In 1905 reinforced concrete began to be developed more intensively. Professor A. F. Loleit designed and erected in Moscow a four-story warehouse with beamless floors. In 1908 the Ministry of Transport issued the first specifications for reinforced concrete structures, and in 1911 approved specifications for the design of reinforced concrete as a result of the work of Professor N. A. Belelyubsky (Russia), Considère (France), Mörsch (Germany), and others. At that time Russian engineers submitted proposals which were widely applied in reinforced concrete structures ; for example N. A. Abramov suggested spiral reinforcement in columns, Professor A. F. Loleit developed the design of continuous beams, and Professor V. P. Nekrasov devised a system of lattice reinforcement.

Before the first world war a department store and the Astoria Hotel in Petrograd (now Leningrad), cement plants in Novorossiisk and Podolsk, and many other buildings were built in reinforced concrete. Reinforced concrete also began to be widely used for bridges at that time. For example, on the Chinese Eastern Railway, Russian engineers built reinforced concrete bridges that were precast elsewhere and brought by railway to the site. In 1912 Academician G. P. Peredery published a work on reinforced concrete bridges.

After the Revolution of October, 1917, concrete and reinforced concrete began to be widely used in the U.S.S.R. In 1921 the first large hydroelectric power station in the country was built on the river Volkhov. The main building was a reinforced concrete frame structure with reinforced concrete arches supporting the track of a 130-tons travelling crane. Between 1927 and 1934 the Dnieper and Svir hydro-electric power stations were built.

In 1927 the State Institute of Construction (now the Central Research Institute of Industrial Construction) was founded, and since then extensive research on concrete and reinforced concrete has been carried out. There are now more than sixty research institutions in the country investigating problems connected with construction. After the first world war and the civil war, when restoration of the wrecked factories began, and later during the period of the first five-years' plan (1928–34) for the development of the national economy of the U.S.S.R. which laid the foundations for the industrialisation of the country, large single-story reinforced concrete factory buildings of frame and arch construction were erected, as well as multiple-story framed buildings with beam-and-girder floors and with beamless floors, silos, embankments, and other constructions.

Since 1928 much use has been made of thin walls and arched and domed roofs. At the Dnieper aluminium works long shells are used for the roof. In Moscow a reinforced concrete dome of 92 ft. diameter (*Fig.* 1) is used for the

roof of the planetarium, and in Novosibirsk there is a reinforced concrete ribless dome of 182 ft. diameter over the auditorium of a theatre. Professors V. Z. Vlasov, A. A. Gvozdev, P. A. Pasternak, and others, were largely responsible for the development of thin walls based on modular dimensions and of curved roofs.

In 1928–29, on the initiative of G. V. Krasin (Director of the State Institute of Construction) and Professor E. V. Kostyrko, a five-story precast dwelling house was erected in Moscow, with load-bearing walls of large clinker-concrete blocks and precast floors. Subsequently the use of precast concrete has been widely developed for single-story and multiple-story dwellings and industrial buildings. On the basis of the experience of precast dwellings, " Instructions on Precast Reinforced Concrete Construction " were published in the U.S.S.R. in 1933. An indication of the growth of the use of concrete in Russia is given by the fact that whereas in 1924 24 million cubic feet of concrete were placed, in 1933 this had increased to about 212 million cubic feet.

Research on Cement and Concrete.

The use of reinforced concrete on a large scale called for increased research. Of great theoretical importance were the works of Academician A. A. Baikov, developed in recent years by Academician P. A. Rebinder, on the setting and hardening of cements, and research was conducted by K. S. Zavriev (Member of the Academy of Sciences of the Georgian S.S.R.), and Moscow scientists, including Professors B. G. Skramtayev, N. A. Popov, and others, on the constitution of cement and on concrete mixtures.

Prior to 1931 Russian Portland cement concrete generally had a compressive strength of 160 to 200 kg. per square centimetre (2270 to 2840 lb. per square inch). By the middle of 1932 this had been increased to 275 to 400 kg. per square

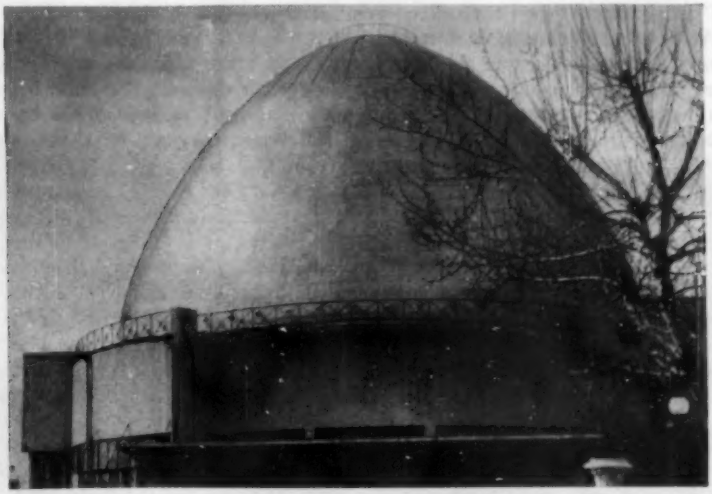


Fig. 1.—Planetarium at Moscow.

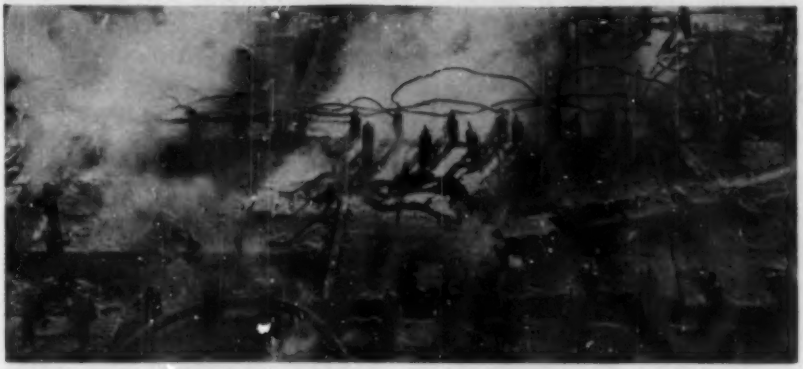


Fig. 2.—Concreting at — 35 deg. Centigrade.

The concrete was cast in " vacuum " shutters to remove excess water. Snow was removed from the shuttering by jets of compressed air. The concrete materials were heated, the mixed concrete was heated by electrical coils during transport from the mixers to the shutters, and when it was placed the concrete was kept warm by electrical heating panels.

centimetre (3900 to 5680 lb. per square inch). With the cement of 1926 it was common to use 350 to 400 kg. of cement per cubic metre of concrete (590 to 756 lb. per cubic yard), but in 1932 it was not permitted to use more than 250 kg. of cement per cubic yard (420 lb. per cubic yard) in concrete with a compressive strength of 110 kg. per square centimetre (1570 lb. per square inch). To-day concrete with a compressive strength of 700 kg. per square centimetre (10,000 lb. per square inch) is obtained.

Ordinary and high-strength Portland cements, Portland blastfurnace cement, high-alumina, hydrophobic, and plasticised cements are available. With the aim of reducing the period of curing of precast units the production of quick-setting cement has started. Precast concrete structural members are made with compressive strengths up to 500 kg. per square centimetre (7140 lb. per square inch).

Over the greater part of the Soviet Union the winters are severe and, in order to carry on concreting all the year round, it was necessary to study the problem of concreting in cold weather. With the use of the so-called " thermos " method and by steam and electric heating the winters are no longer an obstacle (*Fig.* 2). In recent years use has been made of reinforced concretes with high salt content which will harden at temperatures as low as 25 deg. C. below zero. Important research on concreting in winter conditions has been carried out by Professor S. A. Mironov and B. G. Skramtaev, V. N. Sizov, I. G. Sovalov, and others.

Concrete made with lightweight artificial or natural aggregates are much used, and are made by processes devised in the U.S.S.R. by Professor N. A. Popov and by specialists in Georgia and Armenia where lightweight natural aggregates are available in the form of pumice and tuff. Lightweight concretes containing either natural or artificial lightweight aggregates are used for the manufacture of load-bearing members such as floor and wall panels.

From 1932 onwards cellular concrete made with cement and a foaming agent

has been widely used. Thanks to the researches of I. T. Kudryashov, cellular concrete is made from a mixture of cement and ground sand steamed under pressure in an autoclave. In 1939 the first factory for the production of cellular concrete was built in Chelyabinsk, and products are made with autoclaved cellular concrete, cellular silicate concrete, clinker concrete, and so forth, with a density of up to 1200 kg. per cubic metre (78 lb. per cubic foot) and a strength of up to 150 kg. per square centimetre (2130 lb. per square inch).

The production of acid-proof concretes has been developed, and extensive research is now proceeding on the corrosion of concrete. Professor V. M. Moskvin has established the possibility of using concretes in different aggressive environments and methods of protecting concretes against such aggressions. Dr. K. D. Nekrasov has devised methods of producing refractory concretes capable of withstanding a temperature of 1200 deg. C. Such concretes, incorporating Portland cement, high-alumina cement, and soluble glass, are used for the foundations of blastfurnaces and for purposes for which refractory ceramic tiles are used. Under the direction of Professor V. V. Mikhailov, a strongly-expanding cement has been produced which quickly acquires great strength, and when subjected to heat expands greatly and increases the bond between the concrete and the reinforcement.

In most cases concrete is mixed at automatic plants and consolidated by vibrators and vacuum apparatus. At the Kuibyshev hydroelectric power development 7,840,000 cu. yd. of concrete will be placed, and at the Stalingrad power plant 9,139,000 cu. yd. Researches on methods of placing concrete have been conducted by Dr. V. S. Shestoperov, Dr. A. E. Desov, Mr. O. A. Gershberg, and others.

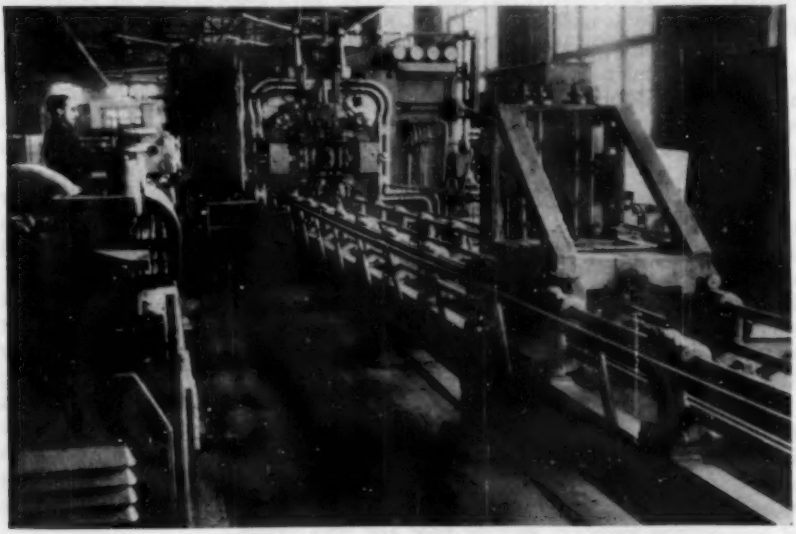


Fig. 3.—An Automatic Machine for Fabricating Reinforcement.

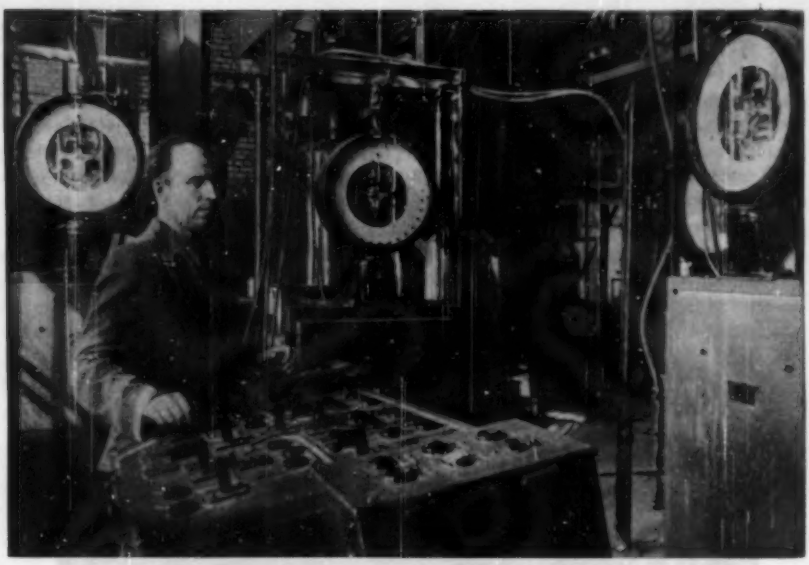


Fig. 4.—Control Room at an Automatic Precast Concrete Factory.

In recent years considerable improvements have been made in the quality of steel reinforcement, most of which is mild steel. The application of welding to reinforcement is an important development. In a number of plants machines (*Fig.* 3) have been installed for the production of reinforcement cages for columns. These machines, which are 160 ft. long and are remotely controlled, automatically measure and cut the bars, straighten them, place them in the required position, and weld the transverse bars to the longitudinal bars. The machines are operated by three men, and a cage for a two-story column is made in from six to seven-and-a-half minutes. Working two shifts a day, one automatic machine produces about 45,000 column cages a year.

Methods of Design.

As the science of reinforced concrete developed, the standards for the design of structures were revised and improved. Between 1921 and 1934 the standards were revised four times. The permissible stresses in concrete and in reinforcement were raised, and factors of safety lowered as the result of improvements in the quality of concrete and steel reinforcement.

In 1931 Professor A. F. Loleit suggested that the method of design should be based on the strength at failure, and research on this subject was undertaken at the Central Research Institute of Industrial Construction. By 1936, under the direction of Professor A. A. Gvozdyev, a method of designing reinforced concrete members by the " ultimate-load " method was produced, and in 1938 this method was introduced into the standards for the design of reinforced concrete structures; this made it possible to estimate more correctly the actual strength of

members and to determine the true factors of safety, and resulted in a considerable saving of steel and concrete. The method was worked out by Professor A. F. Loleit in collaboration with Professors A. A. Gvozdyev, Y. A. Stolyarov, V. I. Murashov, P. A. Pasternak, V. A. Bushkov, and others.

In 1940 Professor V. I. Murashov suggested, and subsequently elaborated, a method of calculating the strength, rigidity, and crack-resisting properties of reinforced concrete, consideration being given to the tensile strength of the concrete between cracks, as well as to the plastic properties of the concrete in compression. At the same time Professor A. A. Gvozdyev, M. S. Borishansky, and others devised a method of calculating the shearing strength of members at failure. This has made it possible to use welded reinforcement without diagonal bars.

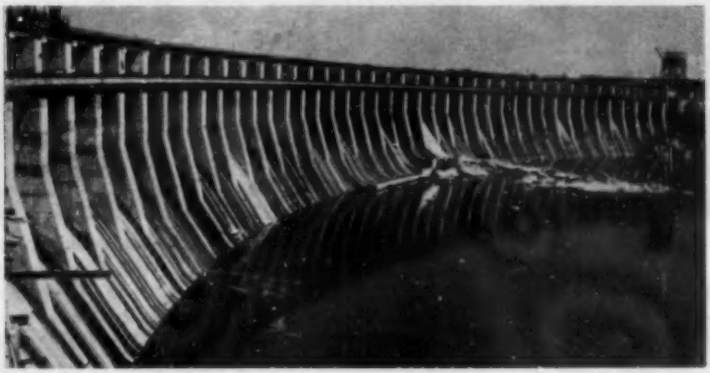


Fig. 5.—The Dnieper Dam as Restored.

In the post-war years a proposal has been submitted for the standardisation of methods of designing structures based on the strength at failure. As a result several working loads have been defined, and factors of safety are based on the possible overloading of a structure, the quality of the materials, and the quality of workmanship. These new rules are for reinforced concrete, steel, brick, and wooden structures and are given in " Building Standards and Rules " issued on January 1, 1955. The principles of the method were produced at the Institute with the collaboration of Professors V. M. Keldysh, N. S. Streletsky, A. A. Gvozdyev, Y. M. Ivanov, I. I. Goldenbalt, and L. I. Onishchik, and Masters of Technical Sciences K. E. Tal, V. A. Baldin, V. M. Kochenov, and others.

Precast Structural Members.

In connection with the further extension of construction work in the U.S.S.R., the need arose for the increased use of precast reinforced concrete, and the production of precast concrete is to be increased from nearly 2,500,000 cu. yd. in 1954 to over 13,000,000 cu. yd. in 1957 ; the rate of progress shows that in 1957 nearly 17,000,000 cu. yd. will be produced. This will make it possible in 1955–56 to erect nearly 70,000,000 sq. ft. of industrial premises and 156,000,000 sq. ft. of

dwelling houses with the use of precast members. For the manufacture of these structures, 602 factories are to be built in the year 1955–56.

Highly-mechanised production is profitable only when accompanied by a large output, and this calls for limitation of the number of different elements to be produced at each factory. For this reason standards are being prepared for story heights and spacing of columns and beams in industrial premises and dwelling houses, and many types of structures with standard dimensions have been designed. In some factories the members are made on conveyors. In Moscow two new plants, each with a capacity of 156,000 cu. yd. a year, are in operation producing floor and wall slabs for multiple-story residential flats, while the other units required for these structures are made at other factories in Moscow. Similar plants with capacities of 156,000 or 78,000 cu. yd. a year are being built in other large cities. In cases where it is required to produce parts for both indus-

Fig. 6.—A Woman Worker on the Dnieper Dam.

trial structures and houses, factories are being erected with differing capacities and with means of quickly changing production from one type of unit to another. Factories are also being built to produce large clinker blocks, as well as dense concrete and cellular concrete wall and floor slabs. The raw materials include fine sands, granular slags, clinker from power stations, and other local materials.

Standard designs have been prepared for different classes of structures, a few examples of which follow. For single-story industrial premises the spacing of the columns is specified as well as the height. The columns are precast, and are of rectangular, T, and I cross sections. Prestressed columns are also used. For the roofs of industrial premises, slabs 20 ft. by 5 ft. or 20 ft. by 10 ft. are recommended. Where thermal insulation is required the edges of the slabs are of dense concrete and the remainder of cellular concrete. For the roofs of structures with bays of 40 ft., 50 ft., and 60 ft., beams are recommended made of separate blocks prestressed together with steel bars. Beams of this type with I-shape cross section are used. Various types of trusses, crane girders, and so

Fig. 7.—Construction with Precast Members.

on, have been standardised in reinforced and prestressed concrete. Standard types of suspended floors have been prepared for several types of structures. These include insulated panels up to 36 sq. yd. in area, with prestressed ribs, hollow panels with circular and oval cores, and solid panels of lightweight concrete; the prestressed panels are the design of Professor V. V. Mikhailov. Use is made of standard bridge beams of prestressed concrete by the method of A. P. Korovin. The beams for one railway are in lengths of 90 ft. to 115 ft. and taken to the site by rail. Reinforced concrete segments were used for lining the tunnels of the Moscow underground railway, and concrete pressure pipes are extensively used.

Precast reinforced concrete structures in the U.S.S.R. are based on extensive standardisation of members and of methods of manufacture, the standardisation of joints, welding of the reinforcement and the joints, and on the use of high-strength concrete. The design of concrete and reinforced concrete and the application of this material are being rapidly developed and are steadily growing. This progress in concrete and reinforced concrete facilitates the fulfilment of the vast amount of work that is proceeding in all branches of construction in order to improve the living standards of the people and to cater more fully for their material and cultural needs.

SWEDEN

By HOLGER ROHFORS

STOCKHOLM.

SWEDEN is a widely extended and thinly-populated country. Nearly all the populated areas have sources of good aggregates, and timber for shuttering is comparatively cheap. Swedish rolling mills do not produce heavy steel sections, but high-class reinforcement steels are made. These are some of the factors which, in conjunction with an ample supply of good Swedish cement, have contributed to the development of concrete on a relatively large scale in Sweden, which has a scattered population of 7,235,000 ; *Fig.* 1 shows the increase in the consumption of cement in recent years.

The manufacture of Portland cement in Sweden started in 1873, and there are now eight works, all but one of which are modern plants with rotary kilns. The average annual production is about 400,000 tons per works. Only Portland cement is generally used in construction. In 1943 the minimum strength at

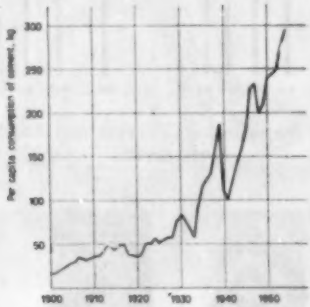


Fig. 1.—Consumption of Portland Cement in Sweden, 1900–1955.

28 days of standard cement, determined on prisms 4 cm. by 4 cm. by 16 cm. (1½ in. by 1½ in. by 6¼ in.) was specified to be 400 kg. per sq. cm. (5700 lb. per square inch). This corresponds to about 450 kg. per sq. cm. (6400 lb. per sq. in.) for cubes of 7 cm. (2¾ in.) sides. Rapid-hardening cement and low-heat cement are also made in Sweden, but the production of these cements does not exceed about 2 per cent. of the total. The manufacture of slag cement on a comparatively small scale was started about two years ago. At present about one-third of the total quantity of cement is delivered loose, mainly in pneumatic containers. In densely-populated areas and near cement works a larger proportion is delivered loose ; for example in the Stockholm district about 60 per cent. is delivered loose.

Standards.

Swedish standard specifications for cement were first issued towards the end of the nineteenth century. The first standards for concrete structures and permissible stresses were published in 1910, and have since been revised several times. Since 1950 the standards apply in principle to all types of concrete structures, and allow progressively higher stresses provided that the work is carefully

done under competent supervision. In 1942 the structures covered by standards were divided into three classes according to the quality of the control and the skill of the workmen. The permissible stresses in concrete and steel are shown in *Fig.* 2. The maximum stresses permitted by the standards of 1942 and 1949 apply only to structures built under special supervision and to Ks40 deformed bars; for other structures the permissible stresses are about the same as those of the code of 1924.

The shortage of materials during the second world war accelerated the trend towards higher stresses in materials. In 1941, for example, the Smedjebacken

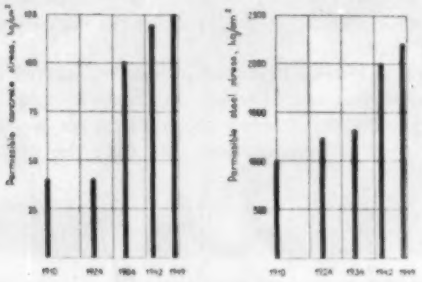


Fig. 2.—Permissible Stresses in Concrete and Steel Reinforcement, 1910–1949.

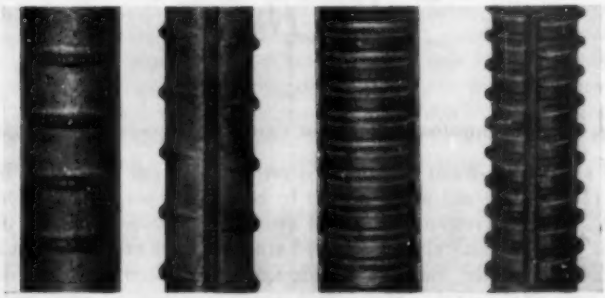


Fig. 3.—Ks40 Bars on Left. Ks60 Bars on Right.

rolling mills produced a special type of deformed bars (Kamjarn)—*Fig.* 3—which provide a higher bond strength and a more favourable distribution of cracks than plain round bars. The distance between the ribs on the Ks60 bar is half as great as that of the ribs on the Ks40 bars, and the ribs are slightly thicker. The maximum permissible stresses in the present standards apply to standard Ks40 deformed bars having a lower yield-point stress of at least 4000 kg. per sq. cm. (57,000 lb. per sq. in.). The saving made possible by the use of deformed bars rapidly increased their applications. At present, "Kamjarn" bars comprise about three-quarters of the total quantity of reinforcement employed in Sweden. The

Ks60 bar has a lower yield-point stress of at least 6000 kg. per sq. cm. (85,000 lb. per sq. in.); this has been in use since 1953 at permissible stresses varying from 3000 to 3300 kg. per sq. cm. (43,000 to 47,000 lb. per sq. in.), but is not yet included in the standards.

Prestressed Concrete.

Prestressed concrete with pre-tensioned wires has been made in Stockholm since 1942. The wire is 2 mm. (0·079 in.) diameter and has a breaking strength of 22,000 to 24,000 kg. per sq. cm. (313,000 lb. to 342,000 lb. per sq. in.). The effective initial tension is normally about 12,000 kg. per sq. cm. (170,000 lb. per sq. in.), and the strength of the concrete at 28 days is 600 to 700 kg. per sq. cm. (8500 lb. to 10,000 lb. per sq. in.). Beams, columns, and other structural members are mostly produced at the factory in Stockholm; the output is about 200,000

Fig. 4.—Prestressed Beams 88 ft. long: Weight 13 tons.

m. (660,000 ft.) of structural elements a year, which are sold all over Sweden. The prestressed beams shown in *Fig.* 4 are 27 m. (88 ft.) long and weigh 13 tons; the greatest length so far used is 31·5 m. (102 ft.). Prestressed beams and columns, used with reinforced lightweight concrete wall and floor slabs (*Fig.* 5), which permit rapid construction, are used on a very large scale. A single-story garage with a floor area of about 10,000 sq. m. (108,000 sq. ft.) required four weeks to erect the prestressed concrete columns and roof beams, with four men and a mobile crane.

The manufacture of prestressed concrete pressure pipes has recently started at two Swedish factories. These are designed and made by methods developed in Sweden. "Sentab" pipes are made in a single operation. *Fig.* 6 shows a test of one of these pipes 500 mm. (20 in.) diameter; the pipes in the foreground are 1200 mm. (4 ft.) diameter. The helical reinforcement is prestressed in the unset concrete by means of an expanding internal rubber core. "Premo" pipes, on the other hand, are made in several stages. First, prestressing wire is wound around a core, and the core is submitted to internal water pressure which extends and tensions the wires. A layer of mortar is then applied to the

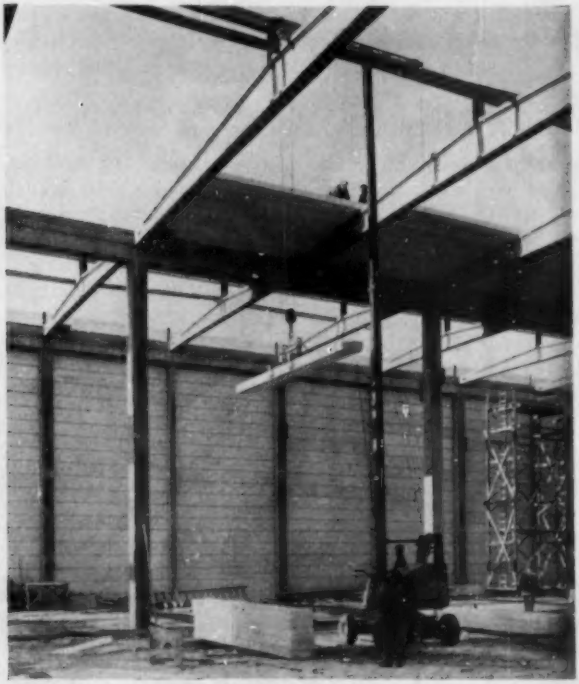


Fig. 5.—Construction with Prestressed Precast Columns and Beams and Precast Concrete Wall and Roof Slabs.

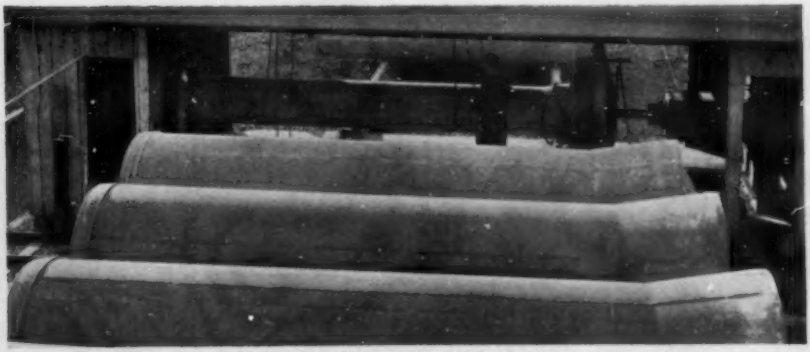


Fig. 6.—Testing a Concrete Pipe.

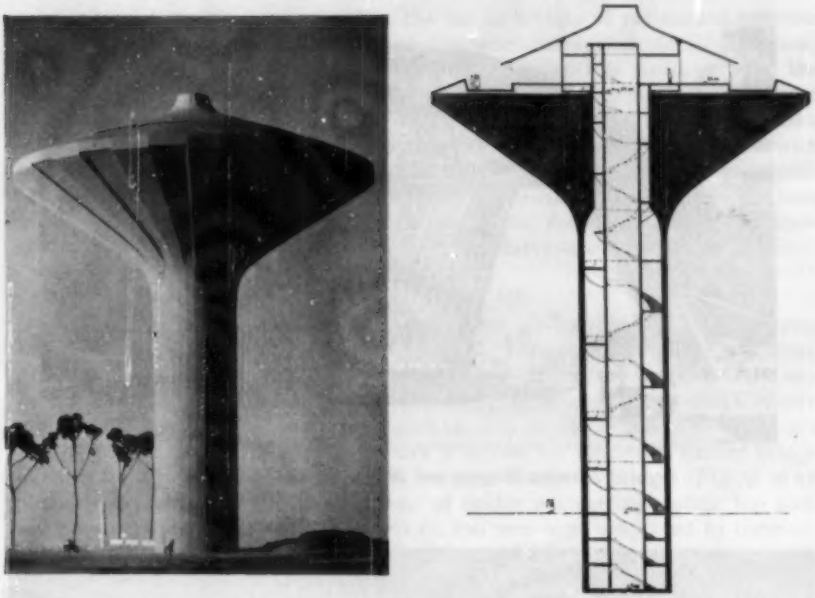
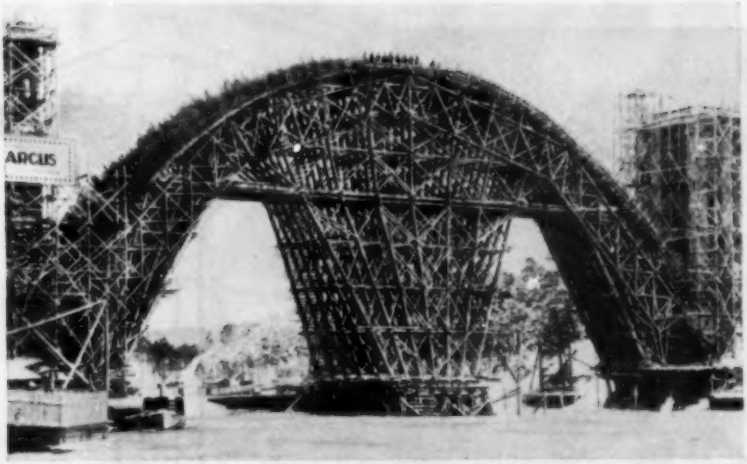


Fig. 7.—Water Tower at Örebro: Model and Cross Section.

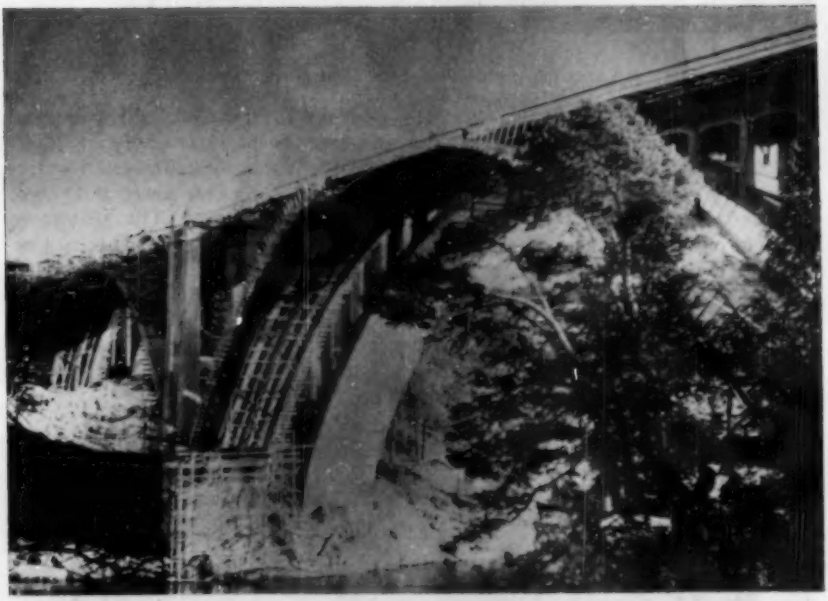
pipe by means of a pressure gun. Prestressed concrete pipes are usually employed at pressures from 8 to 15 atmospheres, and seem to be satisfactory.

Prestressing with post-tensioned steel has been used for bridges and water-towers. *Fig.* 7 shows a model and a cross section of a water tower at Örebro, designed by A.B. Vattenbyggnadsbyrån, now being built. The maximum diameter of the tank is 45 m. (150 ft.) and the diameter of the support is 10·5 m. (35 ft.). The capacity is 8800 cu. m. (2,000,000 gallons). The prestressing cables are anchored in the projections on the wall. The present trend indicates that liquid containers will normally be prestressed in future. In view of the

Fig. 8.—Prestressed Bridge Built on Cantilevered Centering.



Timber Staging and Shuttering used in 1914.



Steel Arch Centering used in 1954.

Fig. 9.—Shuttering used in 1914 and 1954.

relatively high wage rates in Sweden, the use in bridges of prestressed concrete with post-tensioned steel may be expected to be economical in special conditions only, for example when the available construction depth is small or when the span is great. One prestressed bridge in Sweden has so far been built without scaffolding by the Dywidag method (*Fig.* 8). This bridge, built by AB. Skånska Cementgjuteriet at Tunsta, has a span of 106 m. (350 ft.) and is prestressed with post-tensioned bars of 26 mm. (1 in.) diameter. The shuttering was in lengths of 3 m. (10 ft.) and was used seventeen times. This method may become important in Sweden, where the construction of bridges over comparatively wide watercourses would otherwise frequently require expensive scaffolding.

Reinforced Concrete.

BRIDGES.—Boldly-designed concrete arches are probably Sweden's best-known contribution to bridge building. The Traneberg bridge,* Stockholm, of 181 m. (594 ft.) span, was the longest concrete arch in the world when it was built. The bridge at Sandö,† 264 m. (868 ft.) long, is now the longest concrete arch in the world. The first large concrete arch bridge in Sweden, the Skuru bridge, was built in 1914-1915 and, since it is now too narrow, a similar bridge is being built beside it. The difference between these two bridges (*Fig.* 9) is an eloquent expression of the development of bridge engineering during the past forty years. For example, whereas 70 to 100 men were employed in the construction of the old bridge, only 15 to 25 are required to build the new one, and whereas 100,000 cu. ft. of timber shuttering and staging were used in the erection of the first bridge, steel centering is now used. The contractors for the old bridge were AB. Arcus and for the new bridge Nya Asfalt, A.B. The maximum permissible stress in the reinforcement of the first bridge was 800 kg. per sq. cm. (11,300 lb. per sq. in.); in the new bridge use is partly made of deformed bars with a permissible stress of 3000 kg. per sq. cm. (42,600 lb. per sq. in.). The new bridge is 40 per cent. wider than the old, and the permissible moving load has been considerably increased. In spite of this, the deck of the new bridge weighs 2½ tons per linear m. (15 cwt. per linear ft.) less than the old one.

MECHANISATION.—Machines are now much used on building sites. Movable silos for sand and gravel with a weighing device and hoisting equipment, which can handle a truck load at a time, are used on many sites. In the construction of dwellings, about 40 cu. m. (52 cu. yd.) of concrete are placed in eight hours, the batching and mixing plant being operated by one man. Such a plant is too expensive on most sites, and in recent years ready-mixed concrete has come into favour. The first ready-mixed concrete plant was built in Stockholm in 1932, and about twenty are now operating. Truck-mixers are used to deliver concrete from three of these; from the others concrete is delivered in a plastic state in open lorries, the tendency to segregation being sometimes reduced by adding air-entraining agents. Vibration is commonly used for compacting concrete. Nowadays concrete is vibrated in all work of importance, generally with an internal vibrator with a frequency of 10,000 vibrations per minute based on a Swedish invention.

DETERIORATION OF DAMS.—At the time of the first world war, extensive deterioration was observed of some concrete dams exposed to a water pressure

* See this journal for April 1933. † See this journal for January 1949.

on one side only and which were built with dry-tamped 1 : 5 : 7 concrete with a " watertight " layer on the water side. It was found that these defects were caused by water percolating through the dam and leaching out the cement. Since then dams and other exposed structures have been built of denser concrete having a cement content of 300 to 350 kg. per cu. m. (505 lb. to 590 lb. per cu. yd.). Concrete has been much used in water-power development, but the natural conditions of Sweden are not favourable to large concrete dams. The largest concrete dam in Sweden, at Krokström, is 45 m. (148 ft.) high and 160 m. (525 ft.) long. An admixture prepared from albumen was used in the 1930's to improve the workability of concrete in the construction of a dam. The results were so good that

Fig. 10.—Modern Road-making Plant.

this agent, which to some extent has an air-entraining effect, has since been used in all power stations built by the Swedish State Power Board.

CONCRETE IN COLD WEATHER.—In spite of the severe climate, the resistance of concrete to frost has not generally presented problems, except in the case of roads with which trouble was experienced in the middle 1940's. Most roads were made of concrete of fluid consistency, compacted with a screed or lightly tamped. Surface scaling was first observed when salts were added to the sand used to improve resistance to skidding in winter. Roads laid after the second world war were therefore made with stiff concrete which was surface-vibrated. Also, air-entraining agents were added in conformity with American practice. Nevertheless, surface scaling has occurred on a concrete road treated with salt at an age of about two years. It is possible that the air content of 3 to 4 per cent. and the cement content of about 325 kg. per cu. m. (545 lb. per cu. yd.) were too low. This problem is now being investigated. *Fig.* 10 shows a modern

road-making plant, comprising a spreader and a vibrator, both of Swedish manufacture; the slab is 18 cm. (7 in.) thick and reinforced with welded steel mesh. This is typical of roads now being built for heavy traffic in Sweden.

The normal temperature of the air in Sweden is below 5 deg. C. for about six months of the year. Winter concreting was formerly avoided, but in recent years the seasonal variations in the employment of labour have been reduced, partly owing to State intervention. During the period 1935 to 1939, for example, in the month of February the unemployed workers in the building trade were on an average 40 per cent., against 14 per cent. in the same month in the years 1948 to 1952. The sand is heated by steam from a perforated pipe in the storage heap, and the water is heated. Steam is also used to remove ice and

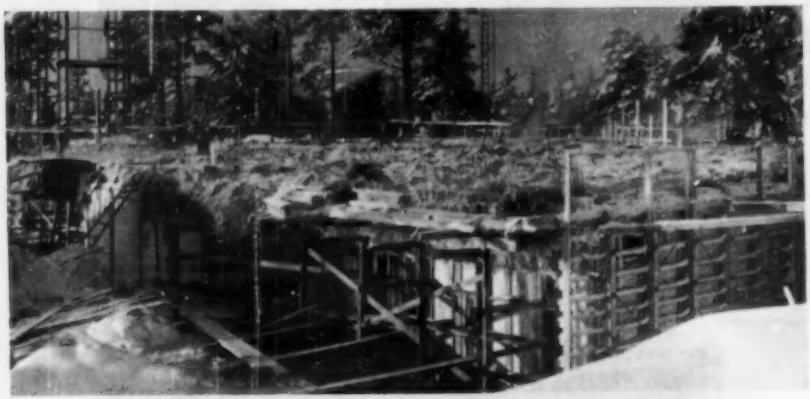


Fig. 11.—Floors Concreted at a Temperature of — 16 deg. C.

snow from the shuttering and reinforcement. In most cases, 1 to 2 per cent. of $CaCl_2$ is added to the concrete, which is made with ordinary cement. The floors of the building shown in *Fig.* 11 were concreted at a temperature of — 16 deg. C. and covered with straw. Concrete construction in the winter is dearer, but this is counterbalanced by a more uniform rate of work throughout the year and by a better use of labour.

SHUTTERING.—Because it was so cheap, wooden shuttering was formerly used once only, but the price is now so high that it has been necessary to revise our views on shuttering materials and methods. *Fig.* 12 shows the increase in cost of some building materials, as issued by Svenska Handelsbanken. The largest quantities of timber shuttering are used in house construction. All apartment houses now have floors of solid two-way reinforced concrete slabs. At present about 40,000 residential flats are built each year, and these require about 3,500,000 sq. m. (37,700,000 sq. ft.) of shuttering for the floors alone. Use is now made of timber or steel posts adjustable in a vertical direction, and of steel girders unsupported between walls which can be used many times. The sheeting is generally in the form of panels measuring 0·6 m. (2 ft.) by 1·5 m. (5 ft.)

made of 1-in. by 4-in. boards. The use of plywood is becoming more frequent, and the smooth surfaces obtained dispense with the need for plastering and rendering. This has led to an increased use of concrete for apartment-house construction. About 10 per cent. of the new apartment houses in Sweden are of cast-in-situ concrete.

PREFABRICATION.—Shortage of labour and the high building costs have con-

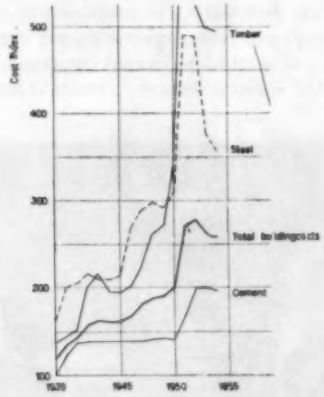


Fig. 12.—Costs of Materials and Building, 1939–1955.

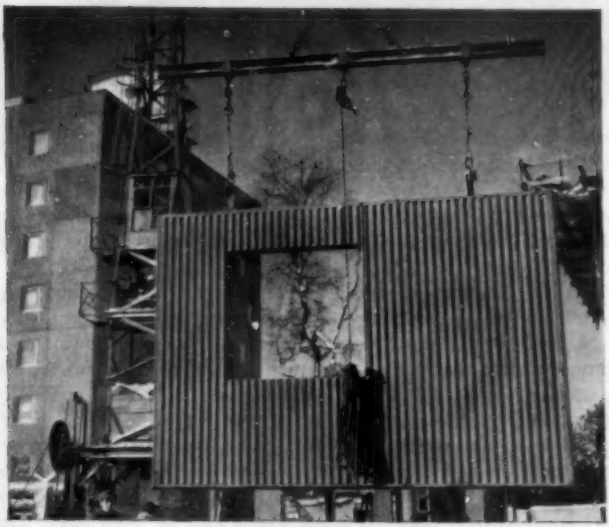


Fig. 13.—Erecting a Wall Panel.

siderably influenced methods of house construction, and full-scale tests are being made on the use of precast elements. *Fig.* 13 shows the use of fine-finished slabs. The concrete frame is cast in situ in shutters with smooth faces, which are erected by crane. These new methods have not yet resulted in any substantial savings in cost, but the labour required on the site and the time of construction have been reduced.

SLIDING FORMS.—Some tall residential buildings have been concreted by

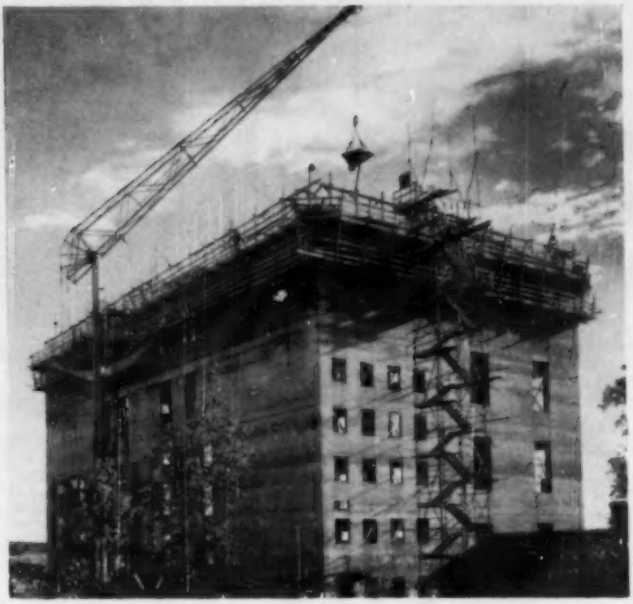


Fig. 14.—Construction with Sliding Shutters.

means of sliding forms, but so far without saving in cost. Sliding forms are, however, used to an increasing extent for other structures, such as silos, chimneys, bridge piers, and head-houses at mines. The forms are raised by hydraulic jacks, a Swedish invention that has been in use since 1946. All the jacks needed for one form are centrally operated by one man, and the forms are raised uniformly and accurately. *Fig.* 14 shows a sliding form in use by the contractors, Svenska Industribyggen A.B., on a factory; the steel roof, weighing 107 tons, was raised with the form.

LIGHTWEIGHT CONCRETE.—Swedish discoveries in high-pressure steam curing of foamed concrete have been of great importance. The Swedish foamed cement concrete, known as Siporex, is based on a discovery, made in the early 1930's, that cement and finely-ground quartz-sand form a calcium monosilicate when they are steam-cured at temperatures above 150 deg. C. Owing to the presence of this compound, foamed concrete has considerable strength, while its density is

low. Moreover, the volume changes of foamed concrete subjected to moistening and drying are almost negligible. Siporex is used for building blocks with, for example, a density of 45 lb. per cubic foot, a permissible stress of 4 to 5 kg. per sq. cm. (57 to 71 lb. per sq. in.), and a thermal conductivity of 0·22. At present, more than 60 per cent. of the outer walls of multiple-story flats in Sweden are made of lightweight concrete blocks and lightweight lime concrete.

Heat-insulating wall-linings made of lightweight concrete blocks are placed

Fig. 15.—Wall of Cast-in-situ Houses.

Fig. 16.—Precast Lightweight Concrete Partitions.

in the shutters so that they become an integral part of the wall. This type of heat insulation has been used almost exclusively in concrete dwellings since the middle 1930's. *Fig.* 15 is a cross section through a typical external wall of a cast-in-situ all-concrete house. The insulation is plastered, generally in colour. The outer wall is generally 15 cm. (6 in.) thick and the insulation 10 cm. to 12·5 cm. (4 in. to 5 in.) thick. The interior party walls are at least 12 cm. (5 in.) thick, and generally unreinforced. Reinforced lightweight slabs, fire-resistant and heat-insulating, are widely employed in precast roofs and walls. Precast partitions (*Fig.* 16) between rooms are the most recent application of lightweight concrete; they are of story-height, 0·5 m. (20 in.) wide and 7 cm. (2¾ in.) thick, and are painted or papered without plaster. The annual production of lightweight concrete in Sweden is about 1,000,000 cu. m. (35,300,000 cu. ft.), about half of which contains cement. "Siporex" foamed concrete is made in five factories in Sweden, and in ten other countries under licence.

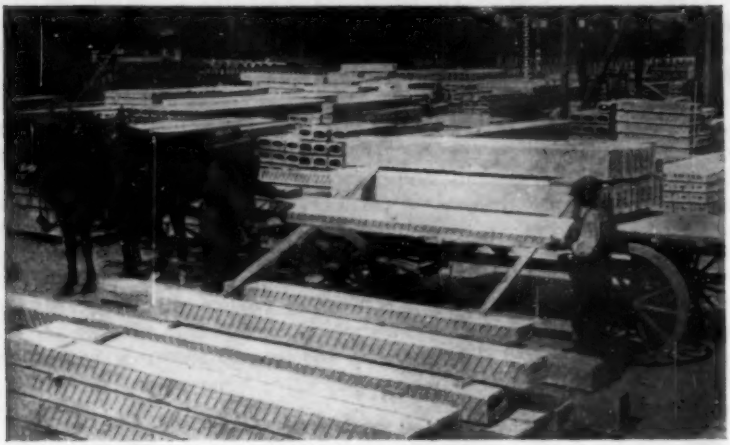
TYPES OF STRUCTURES.—The importance of concrete in Sweden has steadily increased during the first half of this century. A detailed description of the development of concrete is not possible in this article, but a few features may be mentioned. The following, based on data supplied by Cementa, the largest cement marketing concern in Sweden, gives the consumption of cement in various types of construction in the years 1932 and 1953: Residential buildings, shops, offices, and schools, 41 per cent. in 1932 and 38 per cent. in 1953. Industrial buildings, bridges, dams, roads, and harbours, 29 per cent. in 1932 and 27 per cent. in 1953. Precast products, 13 per cent. in 1932 and 29 per cent. in 1953. Farm buildings, 16 per cent. in 1932 and 6 per cent. in 1953. The use of cement on farms has markedly decreased as a consequence of industrialisation, and there has been a considerable increase in the use of concrete products. Products made of dense concrete in 1953 had a value of about 150,000,000 Swedish kronor, of which sewerage pipes of various kinds accounted for more than 50 per cent.; nearly all sewerage and drain pipes from 100 mm. to 2000 mm. (4 in. to 6 ft. 6 in.) diameter are of concrete.

Education and Research.

Valuable contributions to research are made by the Swedish Concrete Association (Svenska Betonföreningen), founded in 1912, and its journal "Betong" ("Concrete"). Professional training courses are organised by the Swedish Cement Association (Svenska Cementföreningen), which was established in 1926 and is financed by the cement industry. During the past ten years training courses have also been subsidised by the State, with the main object of training concrete inspectors; these courses are now conducted by the Swedish Cement and Concrete Research Institute. The training of concrete workers is regarded as an urgent problem, and is now dealt with in schools which are largely financed by the State.

Research has had a substantial share in the achievements of concrete engineering in Sweden, and greater facilities for research have been provided in recent years. The foundation of the Swedish Cement and Concrete Research Institute at the Royal Institute of Technology (Svenska Forskningsinstitutet för Cement och Betong vid Kungl, Tekniska Högskolan), Stockholm, was made possible by a donation made by the cement industry in 1942. Special charges for research are now imposed on nearly all new construction. At present the total of these charges is nearly 2 million kr. (£138,000) a year, which is distributed by the Swedish State Committee for Building Research (Statems Nämnd för Byggnadsforskning) in the form of grants that are used partly to finance research on concrete.

Precast Concrete Fifty Years Ago.



Precast Hollow Beams at a London Works in 1906.

THE NETHERLANDS

By DR. A. M. HAAS

PROFESSOR OF CONCRETE AND CONCRETE CONSTRUCTION, TECHNOLOGICAL UNIVERSITY.

AT the beginning of the twentieth century reinforced concrete was a comparatively new building material that had been used for a number of structures. Its durability, its increasing strength with age, its resistance to corrosion and the weather, and the small (almost negligible) cost of maintenance were soon recognised, but there was an understandable hesitation in applying it to structures generally. This hesitation was due to the scarcity of knowledge of methods of designing and calculating the new material compared with the design of steel structures, which were then frequently built.

First, reinforced concrete is not a homogeneous material, and the calculation of the properties of a non-homogeneous section is more difficult than in the case of a homogeneous section. Secondly, nearly all concrete structures are built monolithically and behave monolithically. This in general results in greater safety and more resistance at the stage of failure, but nearly all concrete structures must be calculated as statically indeterminate. This requires a thorough knowledge of applied mathematics, and it may be noted that, when the principles of applied mathematics had been developed and applied to many types and forms of construction, the design of reinforced concrete became easier and more concrete structures were erected. This is seen, for example, in Professor Hardy Cross's moment-distribution method of design, and in the solution of the more difficult problems of designing shell roofs and statically-indeterminate prestressed concrete structures. In addition, research led to better methods of construction; for example consolidation by vibration and an increasing knowledge of the behaviour of concrete due to shrinkage and creep.

Resistance to Underground Water.

In the low-lying Netherlands concrete has been indispensable in the campaign against underground water. At the beginning of the century concrete was frequently used in the building of cellars and basements. Generally these structures are constantly below ground-water level, and concrete was much superior to the masonry previously used. The Dutch quickly recognised the watertightness and resistance to water pressure of the new material, and many basements were rebuilt in concrete or lined with concrete walls. In the city of Amsterdam alone more than a hundred such basements were built in the year 1897. Gradually reinforced concrete came into use for foundations and water works, such as sluices and quay walls. The early quay walls were designed as massive walls resting on concrete piles; later, lighter cantilevered or T-shape reinforced concrete walls with short or long extended bases were used, sometimes in conjunction with wooden piles.

In many parts of Holland dependable sub-soil is found only at 45 ft. to 65 ft. below sea-level. On such sites concrete piles are used, or concrete caissons are constructed, sunk into place after the layers of soft peat and clay have been removed, and the caissons have been filled with sand. This provides an economical and reliable quay-wall, and has been successfully used for miles of new quays (*Figs.* 1 and 2) in the harbour at Rotterdam.

Fig. 1.—Quays at Rotterdam.

Fig. 2.—Towing Caissons to Position in Quay at Rotterdam.

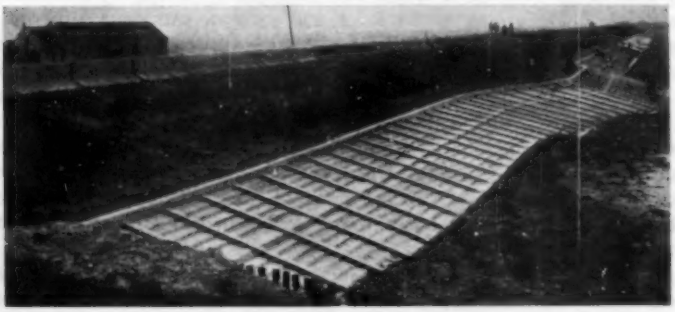


Fig. 3.—Sea Defences at Zeeland.

Sea Defence.

As early as 1904 Mr. de Muralt, a Dutch engineer, invented a method of reinforced concrete construction to protect the outer slopes of exposed dykes. It consisted of a cast-in-situ frame in which concrete slabs were anchored; this proved to be a reliable protection for the faces of sea-defences exposed to smaller and medium wave-actions, and it has been used in Zeeland (*Fig.* 3). An interesting use of concrete is the protection against the extra few feet of high water that may occur at the inland polders, where low parapets of the retaining-wall type (*Fig.* 3) have been built on top of the dykes; openings, which can be closed, are provided to allow the passage of traffic.

In March 1952 the North Sea rose to a level that had not been experienced for five hundred years and parts of Holland and Zeeland were completely flooded. Tidal action greatly enlarged the gaps in the sea defences and it was necessary to close the gaps before the next winter. It was decided that the quickest method

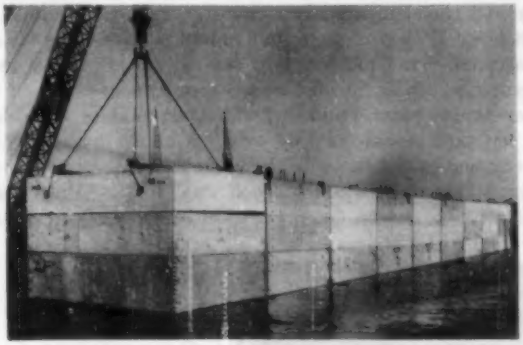


Fig. 4.—Sea-defences at Zeeland.

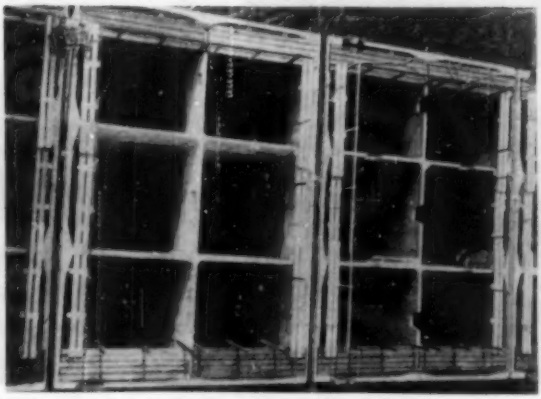


Fig. 5.—Top of Caissons.

was to build many floating caissons, and a total length of about 3500 ft. of concrete caissons was quickly needed. Due to the tidal action the gaps became deeper and broader every day, and it was impossible to decide the dimensions of the caissons required to close any particular gap. Caissons 33 ft. long, 23 ft. wide, and 18 ft. high, with a draught of 6 ft. 6 in. when empty, were chosen as a standard unit. Each consists of six compartments into which wet sand could be pumped for sinking purpose. Where necessary several of these caissons were placed in one gap, and to increase their height separate elements, to be used like huge sleeves or cuffs, were made. All the units were floated to the sites (*Figs.* 4, 5, 6 and 7).

Tunnels.

The increase of vehicular traffic led to the construction of concrete roads, and also made necessary the building of tunnels under rivers and canals. Started before the war, the tunnel at Rotterdam under the river Meuse was completed during the German occupation. In the soft subsoil of Holland the sinking-method was used ; the elements, about 200 ft. long, were made in docks, floated, and sunk into place (*Fig.* 8). A second tunnel is now being constructed under the North Sea canal near Ymuiden, and several other tunnels are projected to relieve the congested traffic in and near Amsterdam.

The Velsen tunnel (near Ymuiden) will accommodate vehicular and railway traffic in two separate tunnels side by side. A choice had to be made between two methods of construction, namely the under-water method and the method of dry excavation. The under-water method used for the Rotterdam tunnel was not considered possible in the neighbourhood of Velsen as it would require the

Fig. 6.—Sea-defences at Zeeland.

Fig. 7.—Sea-defences at Zeeland.

dredging of deep channels in the bottom of the canal as a result of which the fresh water deep down in the soil would be in danger of becoming permanently saline. With the dry-excavation method—which was chosen—the work is done in an excavation which is kept dry by pumping. This method is possible because the soil to a great depth consists of fine sand. The work is being done in two stages. First the tunnel will be constructed to about the middle of the axis of the North Sea canal, followed by the other part (*Figs.* 9, 10, and 11). For the construction of the tunnel sections movable steel shuttering is being used. The concrete is placed by pumps, and is mixed centrally in weighing and mixing plants.

Bridges.

Many concrete bridges have been built across the numerous canals and ditches. These are mostly of the beam-and-slab type. Only a few arch bridges have been built in the Netherlands, and most of these are of the bow-string type. In bridges much importance is attached to the need for a low height of construction

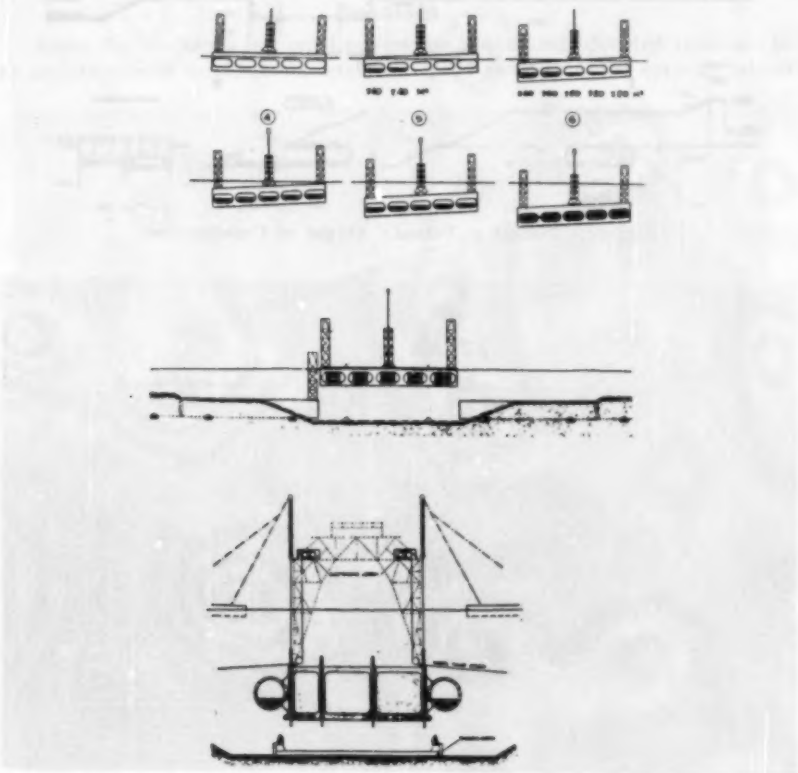


Fig. 8.—Tunnel at Rotterdam : Stages of Sinking Sections.

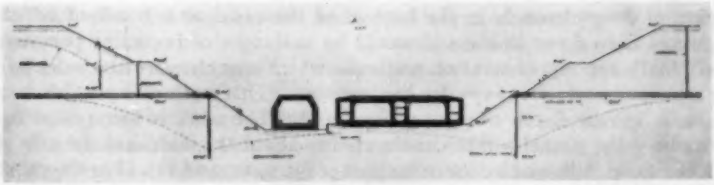


Fig. 9.—Tunnel at Velsen.

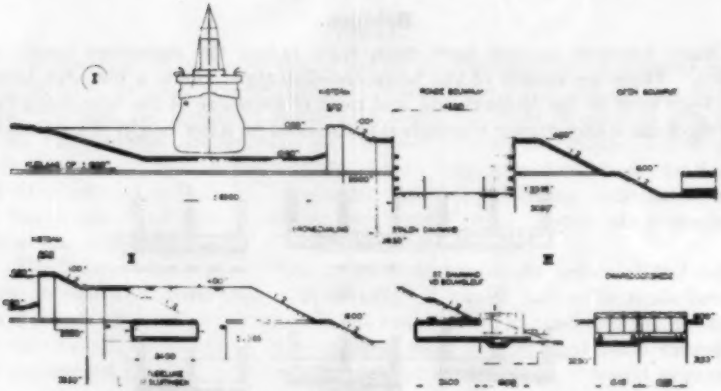


Fig. 10.—Tunnel at Velsen: Stages of Construction.

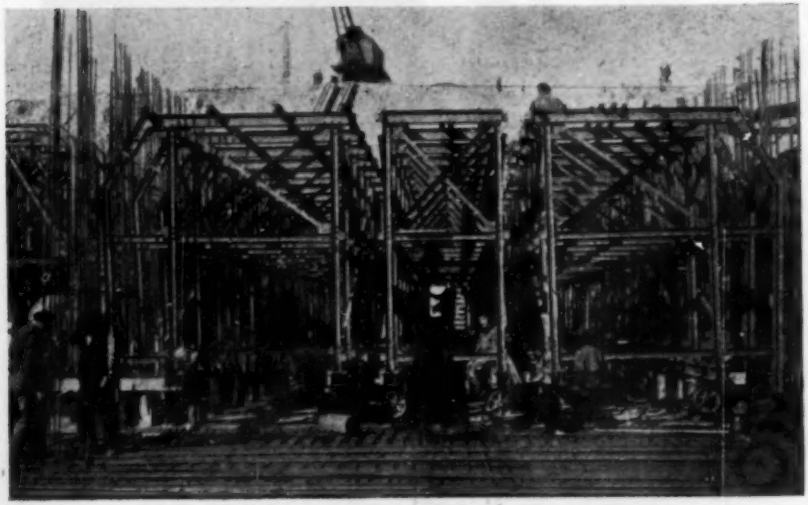


Fig. 11.—Tunnel at Velsen.

Fig. 12.—Amstel Bridge, Amsterdam.

and to a vertical, or almost vertical, loading of the abutments due to the soft subsoil and the flat polderland. For this reason prestressed concrete has been welcomed; a good example is the new Amstel bridge at Amsterdam, with a central span of 185 ft. and with beams continuous over three spans. This bridge (*Fig.* 12) was opened in 1954.

Buildings.

Early this century a few architects in the Netherlands devoted attention to the architecture of reinforced concrete. A good example is the open-air school

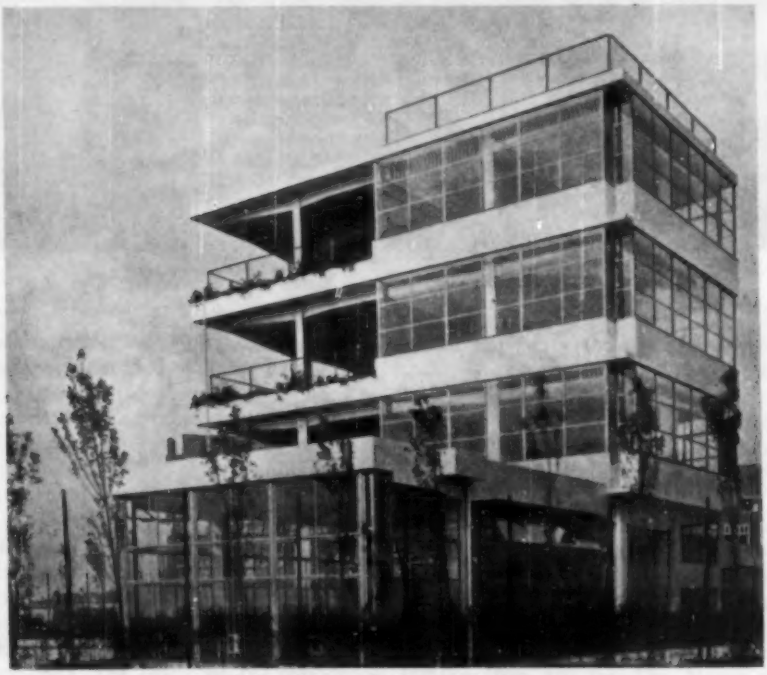


Fig. 13.—An Open-air School.

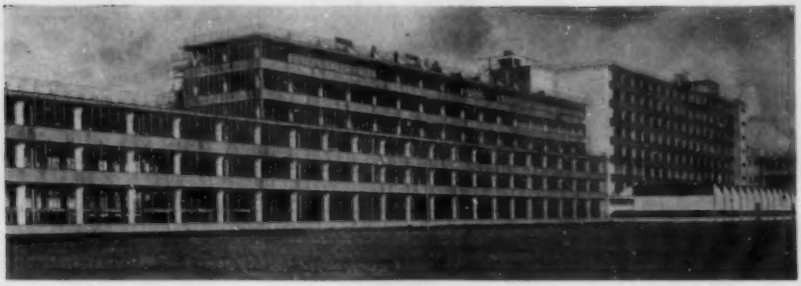


Fig. 14.—Van Nelle Building, Rotterdam.

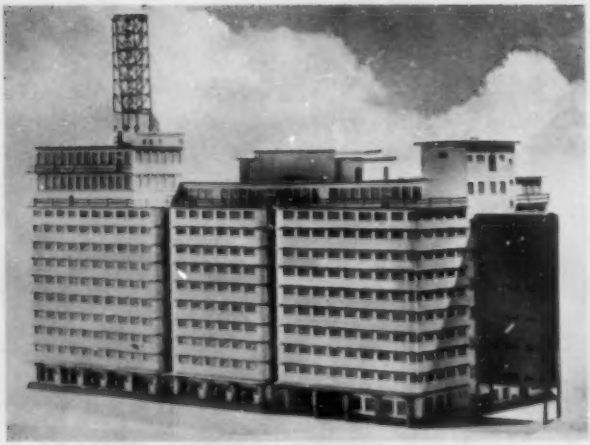


Fig. 15.—Warehouse at Eindhoven.

Fig. 16.—Wholesale Traders' Building, Rotterdam.

(*Fig.* 13) built in Amsterdam some thirty years ago and of which Mr. Duiker was the architect. In this structure part of the reinforced concrete frame is enclosed and part left open to form balconies. The arrangement of the glazing is seen in the illustration ; whilst it is sufficient to define the shape of the part which it encloses, there is enough continuity in the structure to bind the whole into one unit.

In contrast to emphasis on the columns and beams of a frame, the combination of horizontal slabs and vertical supports introduced a new element into architectural expression. Although flat-slab construction had been used for some twenty years, its architectural potentialities seem to have been ignored. Perhaps the Van Nelle factory (*Fig.* 14) at Rotterdam (architects, Messrs. Brinkman

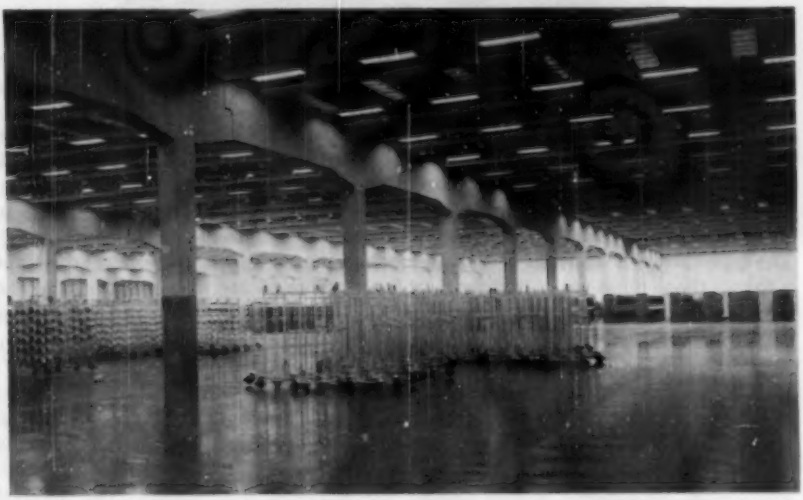


Fig. 17.—Windowless Factory at Emmen.

and van der Vlugt), built in 1929, was the first significant architectural development in this kind of construction in Holland. The continuous glass screen made possible by the absence of columns on the external wall gave rise to new conceptions. Another notable example of this kind is a warehouse (*Fig.* 15) at the Philips works at Eindhoven, a ten-story flat-slab building, also with set-back columns ; the fire-proof dividing walls separate the building into a number of protected storage-blocks.

Concrete has changed the face of our cities, especially in the newly-built areas. In the rebuilt parts of Rotterdam there are many reinforced concrete frame structures with walls of concrete slabs or brickwork. The architects have recognised the potentialities of the material and skilfully applied them. Examples are the new wholesale traders' building (*Fig.* 16) at Rotterdam (the largest in Europe) and a bank recently completed. An important use of prestressed concrete was made in the windowless factory (*Fig.* 17) for Aku Rayon Silk

Fig. 18.—Prestressed Pipes for High Pressures.

Industries,* and also in shell roofs of outstanding spans at the Jamin confectionery works.

More and more methods of precast construction are being used in the Netherlands, where their economy and labour-saving qualities are well recognised. The use of prestressing in the construction of high-pressure pipe-lines (*Fig.* 18), is an outstanding development; these will lead water from the large rivers to the dunes, and provide additional drinking-water to meet the increasing demand. The pipe shown is 16 ft. long, has an internal diameter of 4 ft. 6 in., and weighs 6 tons; these pipes are tested for a water-pressure of 255 lb. per sq. in. and the working pressure is 114 lb. per sq. in.

* See this journal for August 1952.

SPAIN

By A. PAEZ

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The evolution of technology is conditioned by the circumstances of the country in which it is developed; local requirements make necessary specialisation in specific directions, and the repetition of the same problem leads to better solutions as previous efforts are improved. Climate and geography impose their own conditions, and these favour certain tendencies and styles. For example, it would be as absurd to build a mountain hostel in Switzerland with a terraced roof as it would be to construct a building in Andalusia with a high-gabled slate roof.

The art of construction is influenced not only by geography, for the general conditions and primary requirements of a country also cause technology to develop in certain directions. Spain is basically dry and mountainous, and much of the country is unwatered sterile plain, but, thanks to the construction of canals and waterways, in a few years a desert valley may be made fertile. In Spain, rain is often torrential and rivers are extraordinarily irregular; their rate of flow may vary in the ratio of 1 to 10,000. Dams must therefore have disproportionately large spillways. The centering for bridges over rivers is always in danger from exceptional increases in the flow of water. In the Ministry of Public Works, the departments that control and distribute water are of the highest importance. For these reasons, canals, aqueducts, and syphons were the first concrete structures built in Spain. In 1898 Ribera completed the Araxes aqueduct (*Fig.* 1) with 12 m. (40 ft.) spans.

Ribera and Zafra were the pioneers of reinforced concrete in Spain. Ribera was an intuitive engineer whose outstanding intellect made him capable of undertaking the most revolutionary and daring enterprises. Zafra was a theoretician with exceptional analytical powers. He had a profound knowledge of mechanics and methods of calculation, but did little designing; his activity was mainly devoted to teaching and research on elasticity and continuous structures.

Fig. 1.—Aqueduct Built in 1898.

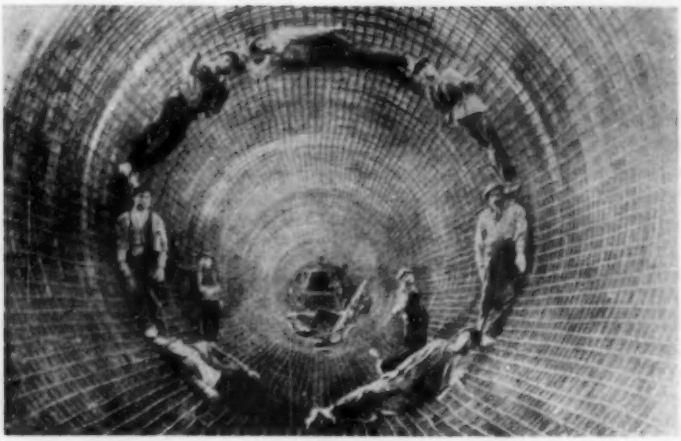

Fig. 2.—Syphon Built in 1903.

Between them Ribera and Zafra awakened the interest of Spanish engineers in the new material. With their complementary qualities they established a basis of theoretical and practical knowledge on which the development of reinforced concrete in Spain was founded. Thanks to these two illustrious men, within a few years an advance was made from the timid achievements typical of the commencement of a new era to the fulfilment of daring enterprises. The Albelda syphon (*Fig.* 2), commissioned in 1903, is 4 m. (13 ft.) diameter, which is considerable even by to-day's standards. The syphon at Sosa, completed in 1906, is 3·8 m. (12 ft. 6 in.) diameter, 1018 m. (3360 ft.) long, and is subjected to a head of water of 28 m. (92 ft.). These works provided useful experience, and were followed by the Guadalete syphon (*Fig.* 3), designed by Gonzalez Quijano.

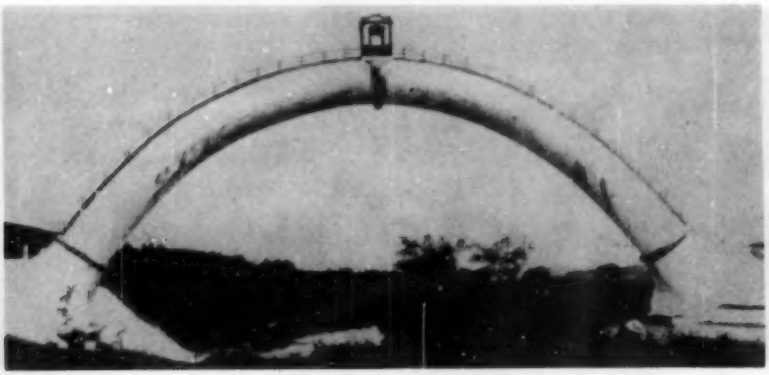

Fig. 3.—Syphon at Guadalete.

the Tardienta aqueduct (*Fig.* 4), designed by Professor Peña, and the Tempul and Alloz aqueducts (by Professor Torroja) about which more will be said later.

Also during the first decade of this century reinforced concrete was applied to bridges. The Maria Cristina bridge (*Fig.* 5), at San Sebastian, was built in 1904, and is the principal work of the period. This bridge has three reinforced concrete arches of 24 m. (80 ft.) span, the rise-to-span ratio being 1 : 11. It is decorated with filigree-like detail; the ease of moulding concrete made it easy to produce capricious decoration, and prevented the designer from evolving a style suitable to the new medium. It was too much to expect that there should have been a simultaneous transformation of building processes and architectural style at a time when baroque cast-iron columns and elaborately carved stone

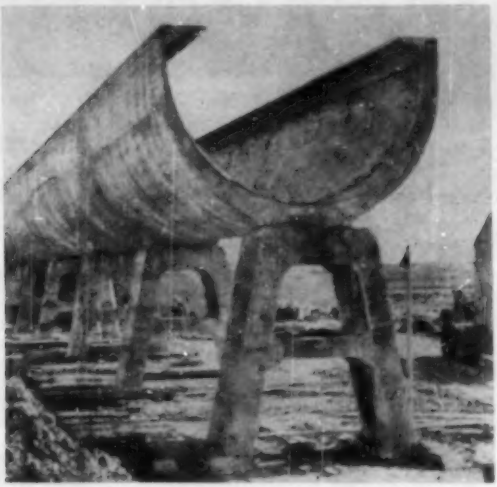

Fig. 4.—Aqueduct at Tardienta.

were the fashion. Ribera and J. Zapata (the architect) who designed this bridge could not liberate themselves from the pompous spirit of their time. The human weakness of trying to appear rich, so typical of the transition from the nineteenth to the twentieth centuries, led to the hiding of the concrete, timid and ashamed, under a face of artificial stone. The piers and abutments, the vaults, the balustrade, and the obelisks, all imitate stone. It was then too early to challenge the opposition of a public not yet educated to the sturdy massiveness of concrete. The frames of the arches consist of L-shape metal sections braced together, and, owing to their rigidity, Ribera was able to concrete each arch along longitudinal chords with the aid of very light centering.

The bridge proved so outstandingly successful that other bridges of the same type quickly followed, and a few years later the Ministry of Public Works approved a series of officially-sponsored bridges of this type. In this group Ribera introduced two important modifications, namely, the spandrels were open, and two arch ribs were used (*Fig.* 6) instead of the slab vault of the first bridge.

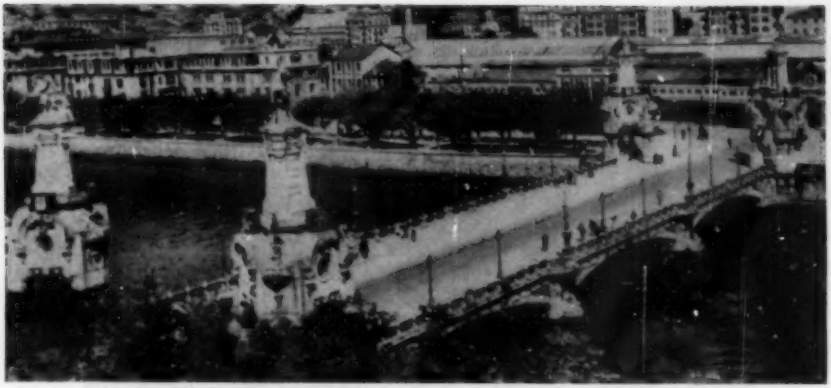

Fig. 5.—Maria Cristina Bridge, San Sebastian. Built in 1904.

Ribera designed an enormous number of similar bridges, with much success. This design was well adapted to the conditions of Spain, where valleys are usually not wide and the deck can be carried by the arch, the foundation soil is usually good so that the ends of the arches can be fixed, and the rigid framework dispenses with the need to erect staging over rivers, which are usually torrential. Both Ribera and Melan claimed the honour of being the first to conceive this type of bridge. Be that as it may, there is no doubt that the frequency with which this design was employed and its suitability to the geographical conditions justify the claim that it is typically Spanish.

During the period 1900 to 1920 engineers did not take into account the deck and its supports in calculating the strength of the arch. Nowadays, being

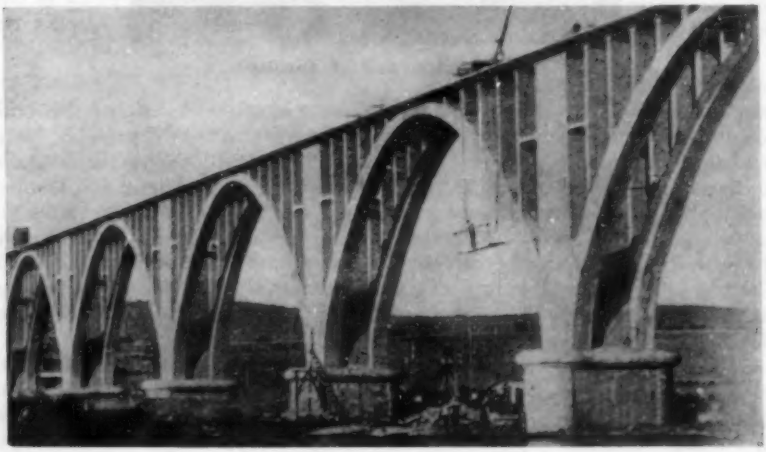

Fig. 6.—Bridge Built about 1910.

more daring than might appear at first sight, the frames formed by the vertical supports of the deck, the longitudinal beams, and the deck itself are assumed to be monolithic with the arch. Ribera considered the arch to be the basic part of the structure, the member on which the deck rests. His bridges, functionally, are the opposite of a slender arch and a rigid deck, a design which, repeatedly adopted elsewhere in Europe, was not favoured in Spain. Again it is a matter of geographical requirements, for bridges with rigid decks do not suit our country ; their construction is not easy over our rivers and ravines. In Spain a drought is followed by heavy rainfall, there is a scarcity of timber, and rivers may in a single week carry more water than during the rest of the year. In a bridge with a rigid deck and a slender arch the centering must remain in place throughout

Fig. 7.—Bridge Built in 1907.

the period of construction, when it is at the mercy of a sudden flood unless it is built so strongly (and consequently expensively) that it can withstand the waters.

Beam-and-slab bridges of reinforced concrete were first constructed in Spain a few years later. From the beginning of the century, wherever the foundations did not permit the use of fixed-ended arches, steel girders were replaced by reinforced concrete beams. In 1907 the first bridge of this type was completed, a bridge (*Fig.* 7) with lattice girders designed by Zafra for the suburban railway in Malaga. About the same time Ribera designed other simply-supported beam-and-slab bridges with T-shape beams.

The bridges of Zafra are reminiscent of metal bridges, while the bridges designed by Ribera are hardly different from those of to-day. Thanks to Zafra's writings, Spanish engineers followed the main contemporary trend of development. Zafra and Ribera began to teach at the College of Civil Engineering in 1910, and their students were to develop with great impetus the teachings of those great masters. Ribera was gifted with a singularly creative intuition, seeking at the same time the maximum ease of construction and the greatest economy. He used the deck connecting the longitudinal girders of a bridge as a compressive member ;

this arrangement is so logical that it is difficult to imagine that a better method will be found of exploiting the structural properties of concrete. One of the properties of these bridges is the substitution of abutments by walls in line with the main longitudinal beams and extending into the embankments beyond the ends of the spans. The beams are extended on to and are supported by these walls, which are cheaper and lighter than the usual abutments. The soil from the approach cuttings is placed on each side of these walls, so that the thrust of the soil on the walls is counteracted.

The spans of the first beam-and-slab bridges were simply supported. Continuous beams and continuously-linked arches were introduced in Spain some years later. This delay was apparently due more to the great success of simply-supported spans than to the doubtful cheapness of continuous spans. Continuous beam-and-slab bridges are economical in material, especially in reinforcement, and the area of the bending moment diagrams is smaller than for simply-supported spans. Also, continuous structures are more elegant than simply-supported independent spans. On the other hand, the simply-supported span has the great advantage of ease of construction. The same centering can be used for several spans, since each can be built independently. The amount of timber required is less, and an overwhelming flood would affect only the span under construction. For these reasons the simply-supported type of multiple-span bridge has been preferred in Spain. Continuous spans, and continuously-arched structures, have been adopted only where foundations are rigid, and where the arch at the crown is so low that a simply-supported span would not be economical.

A feature of this early stage was the unconcern on the part of Spanish engineers about the possible behaviour of concrete for railway bridges. For many years it had been maintained that the vibration produced by trains would in time weaken the bond between the steel and the concrete, but this did not seem to influence the Spanish engineers, since the first beam-and-slab bridges of that time were built to carry railways. The railway bridges by Zafra during the first decade were not satisfactory, but their failure was not due to vibration. The main reinforcement consisted of wide metal strips, and these were the cause of early weakening of the bond. Spanish engineers soon learnt to envelop the laminated strips with wire, to prevent as far as possible the risk of the concrete cracking near the bars, whose cross section should be as compact as possible. Also, special

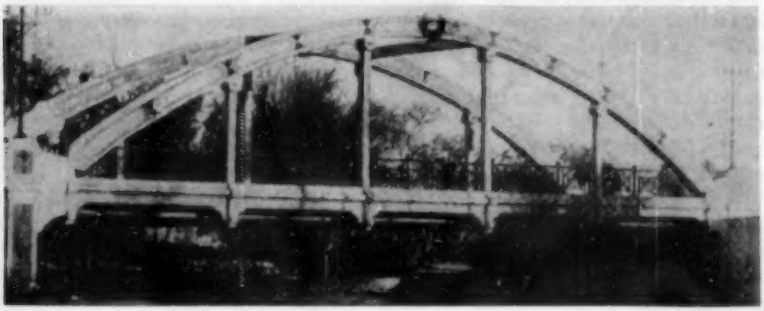

Fig. 8.—Bridge at Iruela. Built in 1912.

Fig. 9.—Aqueduct at Tempul, with Tensioned Cables.

precautions were taken to avoid buckling of the steel, and to ensure that the stresses would be properly transmitted from one material to the other (especially at the joints); the behaviour of the metal within the concrete seemed to be flawless, and the combined structural behaviour proved to be entirely satisfactory.

As the rigid-frame bridges were very successful, whilst the trussed-span bridges were relative failures, the latter were regarded with natural, though unjustified, suspicion; this may account for the fact that Vierendeel girders are scarce in Spain, though widely used in other countries; the complicated shuttering required makes them expensive, particularly in Spain where there is a shortage of timber.

An outstanding date in the history of Spanish bridge-building is the year 1912, when the Iruela bridge (*Fig.* 8) was built; this was the first reinforced concrete hinged bridge in Spain. The suspended deck is carried by parabolic arches, with three joints. Its span is 25·6 m. (84 ft.) between the springings and its rise is 5·1 m. (17 ft.). The two arch ribs are spaced 7 m. (23 ft.) apart, the roadway is 4·9 m. (16 ft.) wide, and there are two footpaths each 1 m. (39 in.) wide. It was not until ten years later that concrete hinges were introduced in Spain, so cast-iron plates and steel rollers were used for the hinges.

Only eight years after the completion of the bridge of Maria Cristina (*Fig.* 5), Spanish engineers became familiar with the application of reinforced concrete for syphons, aqueducts, fixed-ended arches, beam-and-slab spans, and freely-jointed arches. As the years passed a style of its own was developed for reinforced concrete. The spans of bridges became progressively longer, so that the new material replaced metal for more types of structure.

This brings us to 1926, the year in which prestressed concrete appeared. For the purpose of providing Jerez de la Frontera with water, the Compañia de Construcciones Hidraulicas y Civiles had to construct an aqueduct over the river Guadalete, at Tempul. The central span of the aqueduct (*Fig.* 9) was to be 57 m. (188 ft.) long, and in order to save steel this span was arranged to be suspended from the piers by cables, which had to be tightened to compensate for elongation under load. To stretch the cables, Professor Torroja arranged for the top of the columns to be separated from the rest of the structure, and capable of being lifted upwards. The cables from which the aqueduct was suspended passed over this movable top part of the columns, and a month after placing the concrete the tops of the columns were lifted by means of hydraulic jacks, thus tightening the cables. The space between the two parts of the pier was then packed with concrete, the jacks were removed, and the cables were concreted.

The struggle for water, which is the result of our climate, necessitates searching for ever better means of civil engineering construction.

In 1930 a new type of bridge, whose origin can also be regarded as Spanish, was constructed. This is the Narcea bridge (*Fig.* 10), whose deck extends between two arch ribs of 42 m. (140 ft.) span, with ends fixed in the abutments. These arches have one hinge at the crown. The elegance of this design is not incompatible with its low cost. Vierendeel agreed with Sr. Sanchez del Rio, the engineer for this project, that designs based on single-hinged arches may be more economical than others. For rather unaccountable reasons no detailed analysis has been made of the economical possibilities of this type of bridge, nor have its advantages and drawbacks been studied. Two-hinged bowstring arches with suspended decks have been adopted in Spain to span considerable distances where the soil is poor; the number of such bridges in Spain is greater than in flatter countries.

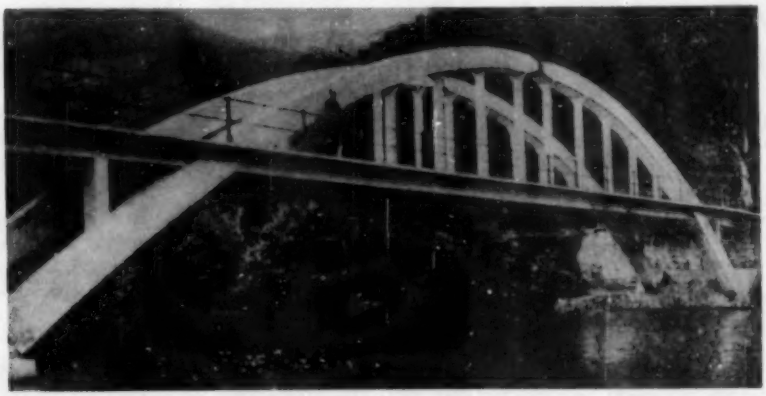

Fig. 10.—Bridge at Narcea.

Perhaps the most typically Spanish contribution to the development of this type of bridge is the proposal of Professor Torroja to tension the tie. The construction of the arch starts with the erection of a self-supporting centering of the Ribera type, as it might be termed (that is a metal centering which will later serve as longitudinal reinforcement for the arch). This centering is hinged at the crown, and from the beginning it is attached to the final tie member. Due to the flexibility of the tie, the arch functions as a three-hinged structure, the horizontal thrust is resisted by the tensile force in the tie, and when the arch is concreted the tie carries a greater load. The hinge at the crown is free until the work is completed. The transverse beams are suspended from the hangers and the deck is concreted, but the ties are left free so that they can adapt themselves to the increasing load. Finally the ties are concreted, the hinge at the crown is closed, and the arch, which under its own load behaved as a three-hinged bowstring, becomes a two-hinged arch acting under the applied loads. In order to achieve more uniform distribution of bending moments along the

Fig. 11.—Bridge at Tordera.

arch, the hinge at the crown of the metal centering is placed suitably off centre with respect to the direction of the concrete arch.

From 1930 Professor Torroja's highly original and successful projects gave a tremendous impetus to this type of structure. The bridges of Posadas and Tordera (*Fig.* 11) indicate his daring spirit. Both are composite structures of reinforced concrete and steel, with spans of 43·45 m. (142 ft.) and 54 m. (178 ft.). The compressive member is the reinforced concrete deck, and the tensile member is an inverted parabolic steel arch. In order to avoid expensive lateral bracing, these inverted arches are attached to the deck by means of V-shaped diagonals (*Fig.* 12).

In 1942 Professor Torroja completed, working with Dr. Villalba and Dr. Salazar, the Esla viaduct (*Fig.* 13) whose central arch of 209 m. (690 ft.) span

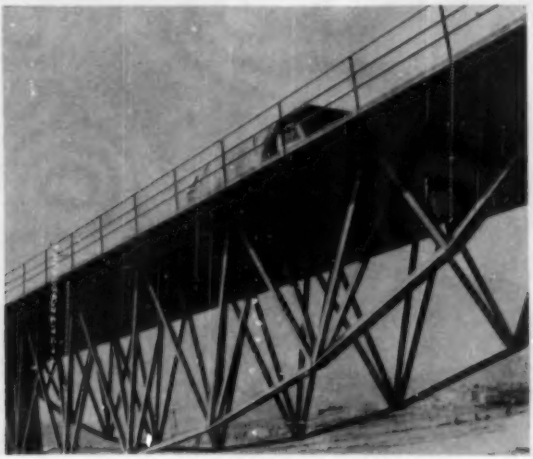

Fig. 12.—Bridge at Tordera.

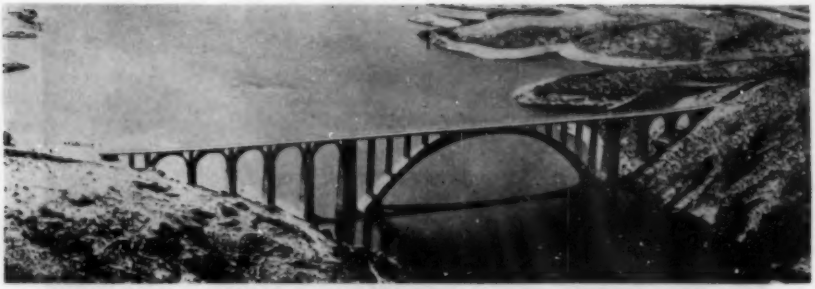

Fig. 13.—The Esla Viaduct: Main Span 690 ft.

crosses the reservoir formed by the Ricobayo dam. This arch is constructed around a rigid frame of the " Ribera " type. For several years it was the longest reinforced concrete arch in the world, and is still the second longest. In this case also steel centering, which became the reinforcement of the arch, was used, as this method was considered the most suitable for constructing arches across the deep Spanish valleys. The forty years between the construction of the Maria Cristina bridge (*Fig.* 5) and the Esla viaduct symbolise the whole development of reinforced concrete in Spain, and a deeply-rooted tradition has been evolved that may justly be termed typically Spanish. In forty years the spans of bridges built in Spain have increased from 20 m. (66 ft.) to 209 m. (690 ft.).

In the erection of thin shell structures Professor Torroja has created most beautiful examples in his very personal style. The Recoletos hall (*Fig.* 14), the market at Algeciras (*Fig.* 16), and the Zarzuela racecourse stands (*Fig.* 15) are

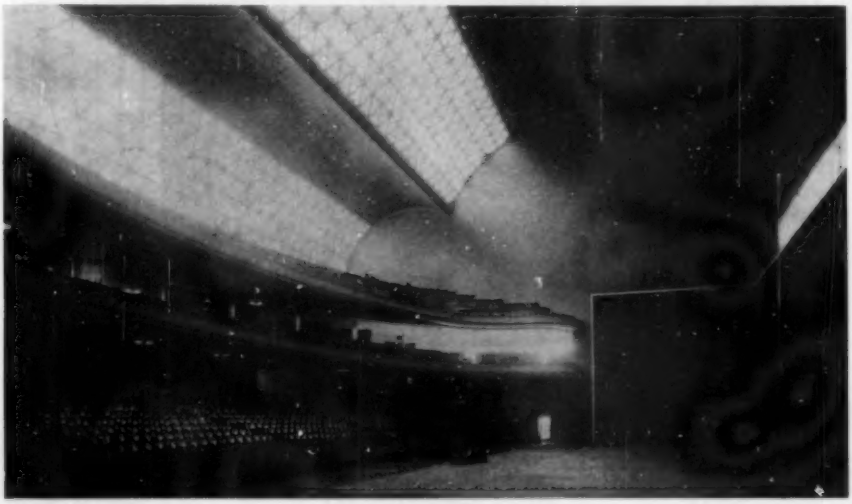

Fig. 14.—The Recoletos Hall.

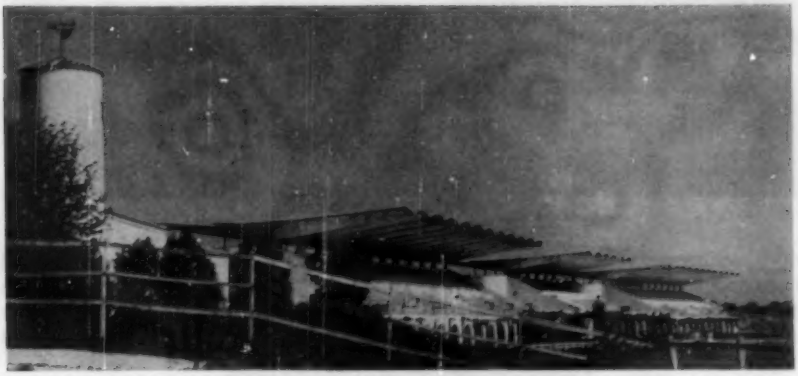

Fig. 15.—Stands at Zarzuela Racecourse.

three brilliant designs to meet three different problems. In these the structures are adapted to the requirements in a strictly functional manner.

In Spain a style of its own has been created for concrete, and the artist is no longer inhibited by the tradition of metal structural forms. It is the conquest of the third dimension. The steel truss, contained in one plane, has given way to the spatial thin shell. Forces are not contained within one member; they extend over a surface. The æsthetic perfection of the market (*Fig.* 16) built at Algeciras in 1934 is due to its naked sincerity of form. Without facing of marble, without adornment, without any concession to what is superfluous, Professor Torroja gives expression in concrete to the equations of three-dimensional equilibrium. A polygonal tie-member, frieze-like, connects the tops of the columns, and

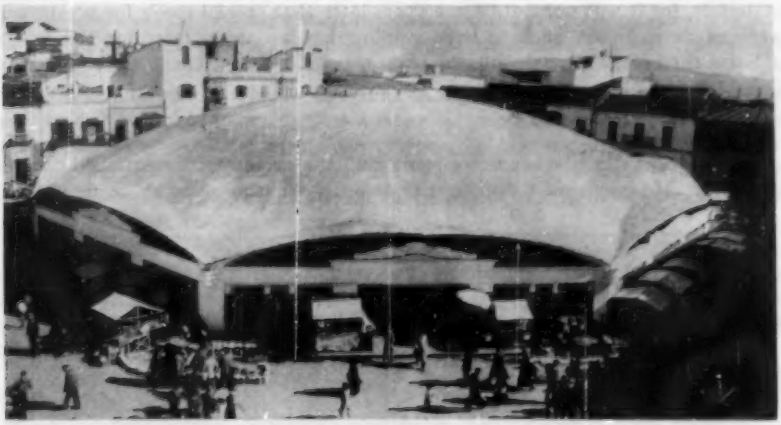

Fig. 16.—Market at Algeciras.

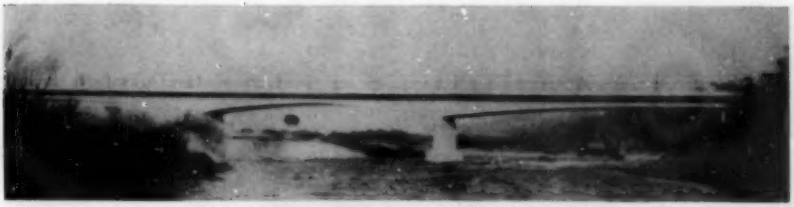

Fig. 17.—Prestressed Bridge at San Celoni.

openings between the cupola and the beam give to the whole an aspect of balanced harmony. The hoop-like tie member prestresses the cupola and lessens the high stresses that would otherwise occur, while the openings are an ingenious device for avoiding the high concentration of stresses that would normally develop where the cupola rests on the peripheral supports.

In the opinion of many experts and artists, the stands at the Zarzuela race-course, built in 1935, represent a new style that has emerged as a result of a new art that seeks the equilibrium of forces through a balanced distribution of masses. In this stand (*Fig.* 15) the structural forces are evident to the observer with the vigour of a Greek discus thrower. As in the Algeciras market building, in this instance too Professor Torroja allows the texture of the concrete surface to be seen untouched. The beauty of the structure depends solely on the harmony of its forms—the naked form has always been the supreme expression of beauty.

Fourteen years after supervising the prestressing of the Tempul aqueduct, Professor Torroja designed the aqueduct at Alloz. This has slender lines, it has an original arrangement for prestressing the cables, and the forces are ideally distributed thanks to a dual form of prestressing. All these features make this an outstanding example of prestressed concrete engineering and of the possibilities of prestressing. As at Tempul, in this aqueduct Professor Torroja employed cables as longitudinal tensile members. This was dictated by the availability of materials, for it was not until some years later that special steels for prestressing were made in Spain, such as were employed a few years later for the bridges of San Celoni (*Fig.* 17) and Almarail (*Fig.* 18), and for the cement silo at Barcelona (*Fig.* 19).

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The works described indicate fairly well the evolution of reinforced concrete in Spain. However, as a summary of this development, it may be desirable to

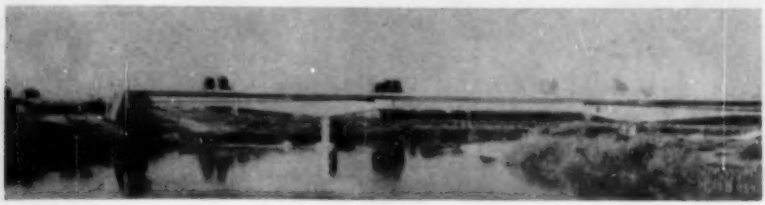


Fig. 18.—Prestressed Bridge at Almarail.

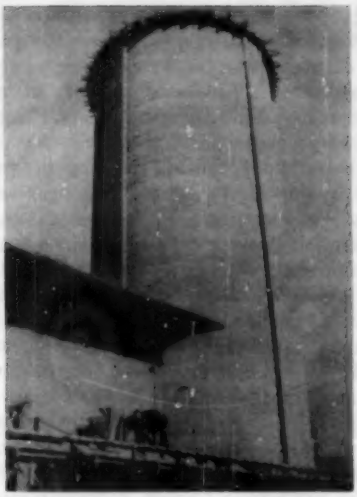


Fig. 19.—Cement Silo at Barcelona.

mention, in general outline, the analytical process and the main features of each period.

As already mentioned, Zafra was the pioneer of the new material in its scientific aspect; he started publishing literature on the subject in 1905, and in 1910 began to lecture at the Civil Engineering College. Zafra was succeeded by Professor Peña in 1923, and from that date a more intensive study was made of the technology and the elastic properties of concrete, as well as problems of bond, anchorage of reinforcement, and so on. At that time concrete was regarded as a perfectly elastic body in which deformation was proportional to stress, and continuous structures were designed as elastic masses. At about that period the official standard types of reinforced concrete bridges, edited by Zafra and Peña, were published. The success that this publication attained in regard to road bridges was in direct contrast to the reticence of the railway authorities, who opposed the construction of such bridges. It was necessary to make many tests and wait a long time to make certain that the bridges already in service were satisfactory and that there was no risk that the vibration of trains might weaken the bond between the concrete and the steel.

After the Spanish civil war a period of intensive reconstruction was initiated. Dr. Torroja succeeded Peña as Professor of Reinforced Concrete at the College of Engineering, and Sr. Fernandez Casado, through the medium of his publications, made Professor Hardy Cross's method of design widely known in Spain, and also published data on the "balanced" design of bridges.

The Central Laboratory for Testing Materials in Madrid enlarged its headquarters and, together with the Technical Institute of Construction and Cement, is engaged in research. Concrete is no longer regarded as a solid which obeys Hooke's law. The usual methods of calculating the strength of sections, based

on permissible stresses, are giving way to design based on ultimate loads. Professor Torroja has developed a method based on the parabolic distribution of bending forces in the concrete, and his formulæ are easily applied to the quick design of structural members. Prestressed concrete members are also designed on the basis of loads causing failure without; however, forgetting the limitations imposed by the need to prevent wide cracks.

The criterion of permissible stresses is being progressively discarded. A factor of safety based on working stresses is no longer acceptable, since it does not indicate the real margin of strength available in the material. The Technical Institute of Construction and Cement has studied the question of factors of safety suitable for reinforcement and concrete, and is experimenting with new methods of obtaining practical formulæ based on the rheological behaviour of reinforced concrete.

History is not a mere recapitulation of past events, which, having occurred, cannot be altered. History is something else. It is a source of valuable lessons. It is experience, condensed in the bitter failures of some and the successes and discoveries of others. It is not just to pay tribute only to those who were successful, for often progress is based on the hard lessons learnt from a disaster. A catastrophe such as that of the third water tank in Madrid leaves an indelible mark. Its sad memory emphasises how an oversight can be the cause of very high local stresses. Calculations give a correct solution only when they are correctly and intelligently made. But theoretical predetermination is very discreet! On its own initiative it does not investigate all possible alternatives or show how precariously stable may be a given state of equilibrium.

In the course of fifty years a powerful technique has developed, which at last has attained an undoubted personality and style of its own. After fifty years concrete has come of age, by means of brilliant achievements, totally independent of classical design in other materials. To advance still further it is essential to observe how reinforced and prestressed concrete behave in the course of time; how they respond to fatigue, how slowly they deform, how well they last. After fifty years we are still uncertain how effective is concrete in protecting the reinforcement from the weather. To quicken the flow of time we attempt to anticipate the future by means of expensive accelerated tests, which are not always representative of actual phenomena.

Engineers must still study history.

SWITZERLAND

By PROFESSOR M. ROŠ

ZÜRICH.

Development and Progress.

The development of reinforced concrete in Switzerland during the last fifty years has been due to

(1) The improvement in the properties of Portland cement (*Table* I) and consequently of concrete (*Table* II), including improved methods of making and placing concrete.

(2) The raising of the elastic limit of steel reinforcement (*Table* III), and so improving the ductility, tensile strength, and fatigue limit while maintaining the capacity for deformation, as for example in forming hooks and bending bars.[7]

(3) The increase in the bond between concrete and steel under static and dynamic loads resulting from suitable disposition of bars. This produces a monolithic unity and a reduction in the width of cracks, due to their being numerous and closely spaced. The width of the cracks is approaching a tolerable

TABLE I.—SWISS STANDARDS FOR PORTLAND CEMENT.

STRENGTH IN Kg. PER SQ.CM. & LB. PER SQ.IN. FOR SPECIMENS OF 1:3 MORTAR

	YEAR	1900	1919	1925	1933		1945/53
NORMAL CEMENT	DIRECT TENSION	22 Kg. 310 lb.	22 kg. 310 lb.	28 kg. 400 lb.	33 kg. 470 lb.		
	TENSION IN BENDING					45 kg. 640 lb.	65 kg. 925 lb.
	COMPRESSION	220 kg. 3100 lb.	260 kg. 3700 lb.	325 kg. 4600 lb.	460 kg. 6500 lb.	275 kg. 3900 lb.	400 kg. 5700 lb.
HIGH STRENGTH CEMENT	DIRECT TENSION			40 kg. 570 lb.	45 kg. 640 lb.		
	TENSION IN BENDING					60 kg. 850 lb.	75 kg. 1070 lb.
	COMPRESSION			650 kg. 9250 lb.	700 kg. 10,000 lb.	420 kg. 6000 lb.	590 kg. 8400 lb.

Since 1933 tests have been made on 4-cm. by 4-cm. by 16-cm. bars. Earth-moist mortars were used up to 1933, since when plastic mortars have been used. Sand of one grain size was used up to 1945, since when sands of three grain-sizes have been used.

TABLE II.—STRESSES IN CONCRETE.

STRENGTH AT 28 DAYS IN Kg. PER SQ.CM. & LB. PER SQ.IN.

	GRADE OF CONCRETE			
	I NORMAL	II HIGH STRENGTH	III VIBRATED	IV VIBRATED PRESTRESSED
COMPRESSIVE STRENGTH OF CUBES	220 kg. 3100 lb.	300 kg. 4300 lb.	500 kg. 7100 lb.	600 kg. 8500 lb.
" " " PRISMS	175 kg. 2500 lb.	240 kg. 3400 lb.	400 kg. 5700 lb.	480 kg. 6800 lb.
BENDING " " "	35 kg 500 lb.	45 kg. 640 lb.	55 kg. 780 lb.	60 kg. 850 lb.
TENSILE " " "	23 kg 330 lb.	27 kg. 380 lb.	33 kg. 470 lb.	38 kg. 540 lb.
TOLERANCE IN COMPRESSIVE STRENGTH	25%	20%	15%	10%

limit of about $\frac{1}{3}$ mm. (0·013 in.), and this has been achieved by using bars of small diameter distributed throughout the tensile zone and where possible following the lines of principal stress or by prestressing the tensiie zone.

(4) The rational use of the properties of steel and concrete.

(5) Tests carried out on structures and experience gained during their use.[1]

(6) A logical interpretation of the theory of reinforced concrete[2] which takes into account the particular properties of both steel and concrete; this knowledge has been gained by laboratory tests and on building sites.[3]

(7) Mastery of the use of the combination of concrete and steel; and

(8) Improvements in methods of construction.

Increasing the apparent elastic limit (ductility) of steel is not alone of overriding importance, as other mechanical properties are desirable, including (a) lack of brittleness; (b) high resistance to fatigue (particularly in the case of high-tensile steel); (c) ease of forming bends; (d) the ease with which concrete may be placed around and bonded to the steel (this is influenced by the shape and spacing of the bars) even in the case of the unavoidably small movements of concrete due to shrinkage or to the deflection of shutters during concreting; (e) good bond between the steel and concrete ensuring complete unity of action between the two materials and so allowing the elimination of hooks,[3] and reduction of the equivalent grip-length,[4] leading to a reduction in the width of cracks; (f) the elimination of splitting of the concrete due to the shape of the reinforcement, such as might occur if a sharp angle bears against the concrete (for example, in the case of twisted bars of rectangular cross section); (g) deformations caused by shrinking and creep of concrete; and (h) relaxation of the steel, particularly in the case of prestressed concrete.

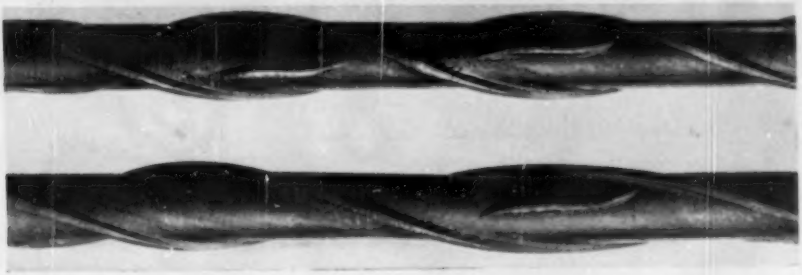
TABLE III.—MAKERS' GUARANTEED PROPERTIES OF STEEL.

Group	Quality of Steel		Minimum Values: Apparent elastic limit kg. per sq. mm. (lb. per sq. in.)	Tensile strength kg. per sq. mm. (lb. per sq. in.)	Extension at Failure λ_5 Per cent.	λ_{10}	Reduction in cross-section area at failure Per cent.	Bending coef. $50\frac{d}{r}$ cracking in zones of tension	Bending coef. $50\frac{d}{r}$ cracking in zones of compression	Number of reversals of bending. Radius = 5dia.	Maximum allowable stress during fabrication kg. per sq. cm. (lb. per sq. in.)
I	$A_c N$ Normal mild.		24 (34,000)	36 (51,000)	25		50	80	40		
II	High Tensile. 1.– A_c TOR 40 cold twisted (12 dia.)		36 (51,000)	45 (64,000)	14		45	80	40		
	2.– A_c 54 normal hardness, smooth.		36 (51,000)	52 (74,000)	20		45	80	40		
III	Very High Tensile A_c TOR 60 cold twisted (9 dia.)		54 (76,500)	65 (92,500)	12		40	70	35		
IV	Wire. Smooth or indented for prestressed concrete.	Dia. (mm.)			λ_5	λ_{10}					
		2	152 (216,000)	190 (270,000)	6	4	30	–	–	4	12600 (179,000)
		3	140 (199,000)	175 (250,000)	6	4	30	–	–	4	11,600 (165,000)
		4	128 (182,000)	160 (227,000)	6	4	30	–	–	4	10, 600 (150,000)
		5	120 (170,000)	150 (213,000)	6	4	30	–	–	4	10 000 (142,000)
		6	112 (160,000)	142 (200,000)	6	4	30	Min. 40		–	9400 (134,000)
		7	108 (153,000)	135 (190,000)	6	4	30	Min. 40		–	9000 (128,000)

[λ_5 and λ_{10} are the extensions measured over 5 and 10 diameters respectively.]

Qualities of Concrete and Steel.

There are to-day four types of reinforcement (*Table* III) and qualities of concrete (*Table* II) available in Switzerland, namely: Group I—Mild steel (AcN) of normal hardness and with a smooth surface. Group II (1)—High-tensile steel obtained by cold-working of mild steel,[3] [6] for example by torsion as in the case of AcTor 40 with two continuous helicoidal ribs (*Figs.* 1, 2 and 3) and with short ribs on one side (the pitch of the helices is 12 diameters). Group II (2)—High-tensile steel (Ac54) of normal hardness and with a smooth surface. Group III—Very high-tensile steel (AcTor 60), obtained by cold twisting steel



Figs. 1 and 2.—Top: AcTor 40 (Group II). Bottom: AcTor 60 (Group III)

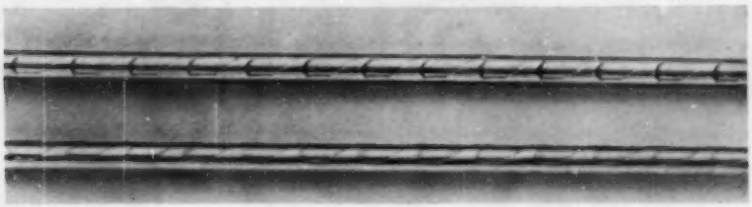


Fig. 3.—AcBBR (Group IV).

Fig. 4.—Railway Viaduct at Fribourg. Spans up to 160 ft. Built 1925–1927. Engineers: Direction Générale C.C.F.

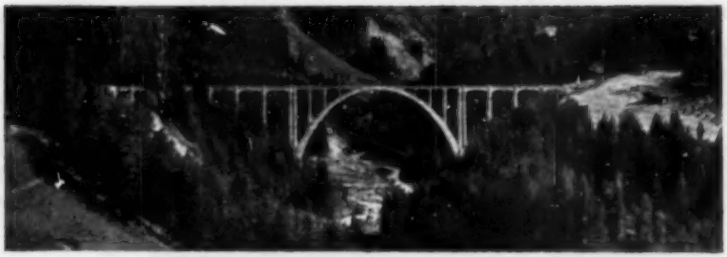


Fig. 5.—Railway Bridge near Langweiss. Built 1912–1915. Span 330 ft. Built 1912–1915. Engineer : R. Maillart.

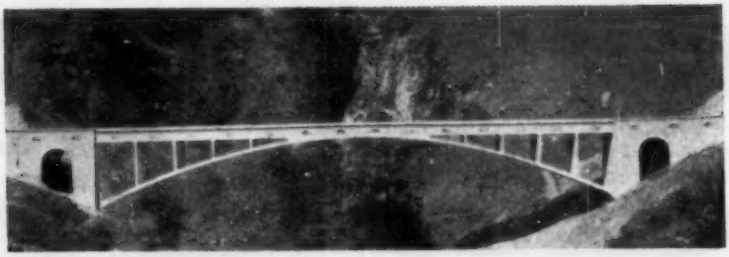


Fig. 6.—Road Bridge at Donath. Span 142 ft. Built 1925. Engineer : R. Maillart.

Fig. 7.—Road Bridge at Champel Very (1937).

Fig. 3.—Road Bridge at Schiers. Span 290 ft. Engineer: R. Maillart.

Ac54 with two continuous helical ribs and short ribs on both sides. The pitch of the helice is 9 diameters. Group IV—Special steel of very high-tensile strength obtained by heat treatment combined with cold stretching (AcBBR) with stamped or rolled indentations, followed by tempering.

Laboratory tests and experience justify the conclusion that reinforcement of Group I may be of good Thomas quality, but for Groups II (2), III, and IV steel produced by the Siemens-Martin process or by an electric-arc furnace is satisfactory. It is probable that steel produced by the Thomas process but using oxygen will give satisfactory mechanical properties in Group II (1). For each shape of bars the possible effects of indentations on the steel and concrete should be investigated by test.

The four groups of steel correspond to the four qualities of concrete described in *Table* II. In principle the four groups of steels and the corresponding qualities of concrete should be used in conjunction.[5]

Structural members are grouped in two classes, namely Class I, slabs; rectangular, shaped and hollow beams; and Class II, shapes such as T-beams and coffered slabs of smaller cross section than in Class I, and permissible stresses vary according to the quality of the concrete, steel, and workmanship. In

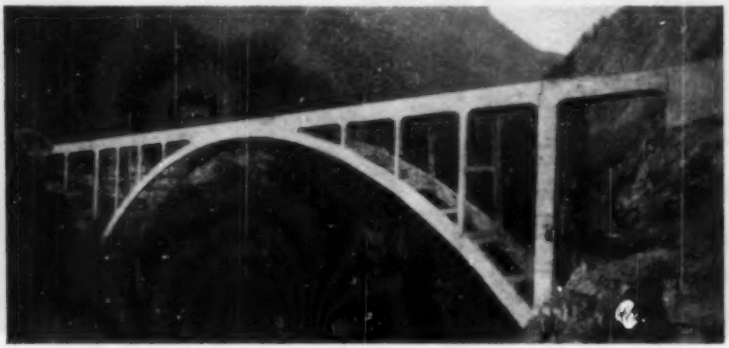


Fig. 9.—Road Bridge near Gueroz: Span 327 ft. Engineer: A. Sarasin.

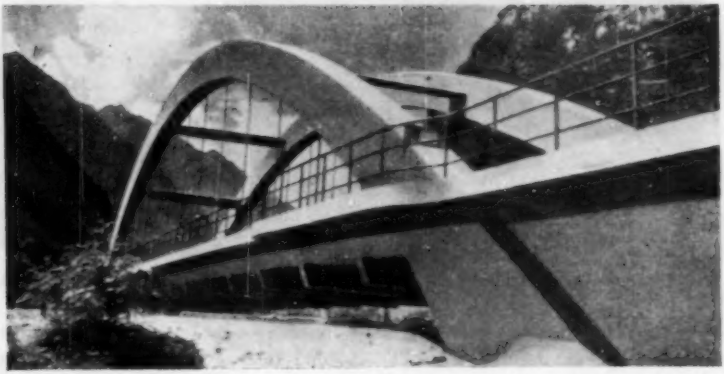


Fig. 10.—Road Bridge near Brasca. Span 255 ft.; rise 50 ft. Engineer: W. Krüsi.

Fig. 11.—Bridge Carrying Four Railway Tracks. Span 490 ft.; rise 113 ft. Engineers: Direction Générale C.C.F.

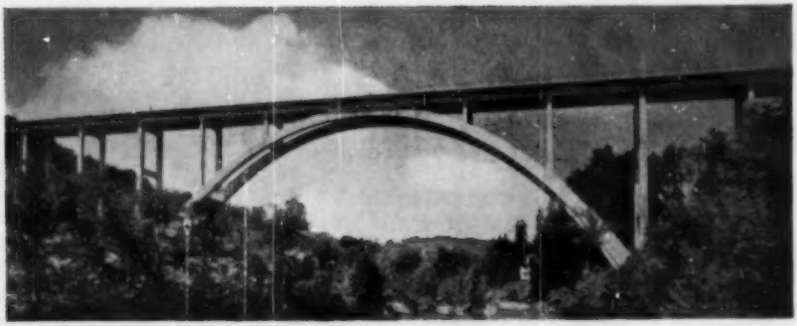


Fig. 12.—Road Bridge at St. Gall. Span 442 ft.; rise 147 ft. Engineer: Ch. Choppard.

all cases the factor of safety is not less than 1·5. The permissible stresses in Class II allow for inaccuracies in placing reinforcement and in the sizes of thinner sections. In the case of beams in Class I in which the amount of reinforcement exceeds that theoretically necessary (that is where the computed tensile stress is less than that permissible) an increase in the compressive stress in the concrete is allowable based upon the difference between the permissible and computed stresses in the steel.

Architecture and Design.

Figs. 4 to 26 show some of the more interesting reinforced concrete structures in Switzerland; they indicate future possibilities, and the problems of the future and their possible solutions. The architecture of reinforced concrete should express the interplay of statical forces and a mastery of the material. Science

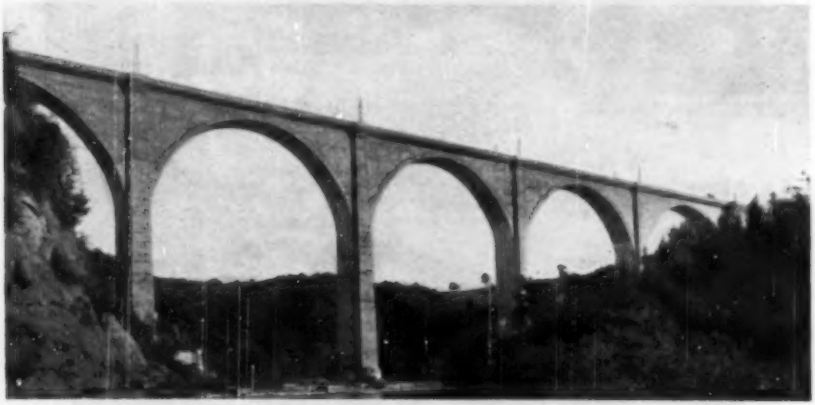


Fig. 13.—Road Bridge at Fribourg. Built 1920–1922. Spans 183 ft. Engineers: Jaeger & Lusser.

Fig. 14.—Flat-slab Floor with 23-ft. spans.
Engineers: W. Stücheli and H. Eichenberger.

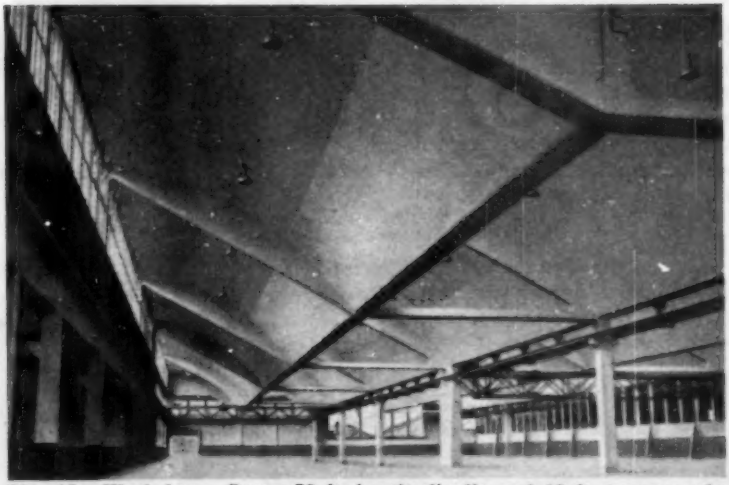


Fig. 15.—Workshop. Spans 78 ft. longitudinally and 69 ft. transversely.
Engineer: H. Schaerer.

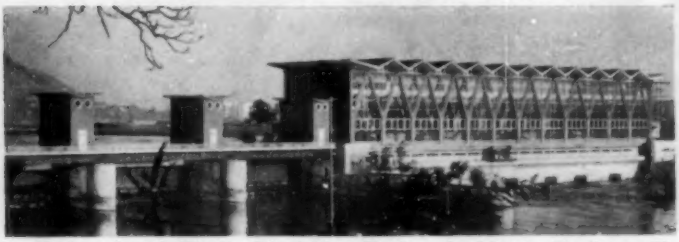


Fig. 16.—Hydro-electric Works, Birsfelden, Basle. Architect: Professor Hofmann.
Engineers: A. Aegerter and Dr. Bosshard.

and art are joined directly. A simple form, with the members cleanly connected, with slabs, beams, and supports logically arranged, dimensioned harmoniously, free from all traditional influences and unhidden by facing materials, is the logical architectural style for concrete. The ways in which the forces are resisted—by concrete in compression and steel in tension—have an essential influence on the general arrangement of the structure and the method of construction, reflecting the constructive spirit and creative will inspired by the material and the cultural way of life that compels progress. The architectural style should express the composite material correctly designed, carefully constructed, based on tests and the strength of materials, and carried out according to well-established principles.

One must recognise the tendency towards a closer relationship between concrete and steel. This trend has reached its optimum in prestressed concrete, which is free from cracks and in which the deformations are sensibly smaller than in reinforced concrete, particularly those due to bending. The performance of prestressed concrete is in reality much more complicated than would appear from the theory. Prestressed concrete is so far the best means of using concrete and

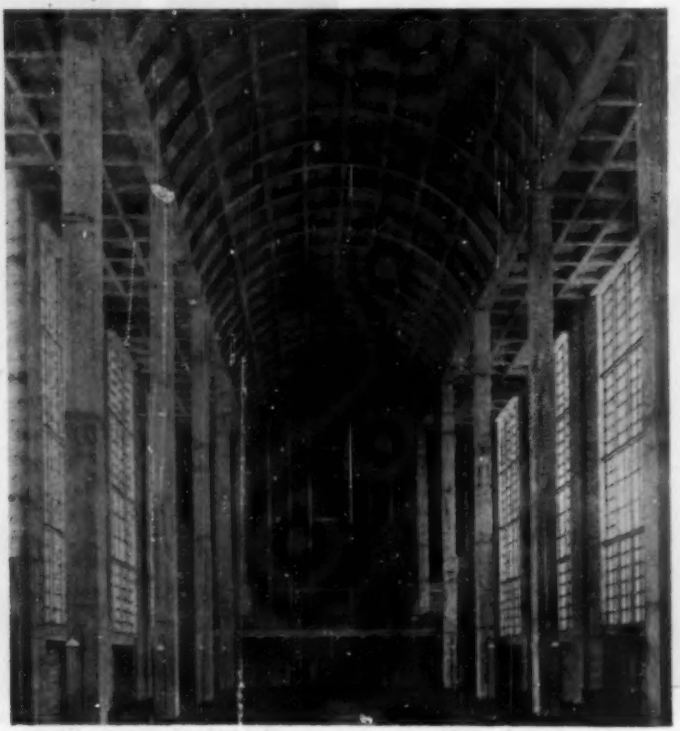


Fig. 17.—Church of St. Antoine, Basle. Built 1927. Engineer : Professor K. Moser.

steel. From the point of view of the stresses within a member, prestressed beams are analogous to arches. The deformations are decreased. The saving of cement and steel is considerable. The possibilities of prestressed concrete are ever widening, particularly for purposes for which concrete would not otherwise be satisfactory. It is the quality of the material and of the workmanship that must be considered.

The considerable improvements in the quality of concrete and steel permit a considerable increase in permissible stresses, and hence more slender construction, with technical advantages and economy. The mathematical conceptions of problems of statics and dynamics are perhaps being relegated to a secondary place, eclipsed by the science of construction and by our mastery of the material,.

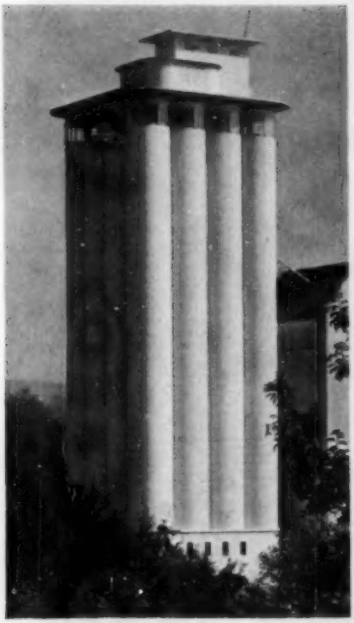


Fig. 18.—Grain Silos at Matzingen. Height 98 ft. Capacity 3000 tons. Engineers: Locher & Cie.

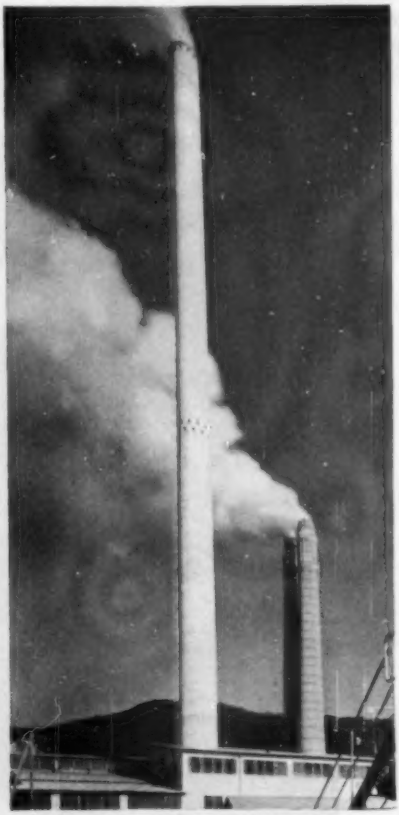


Fig. 19.—Chimney 393 ft. high at Holderbank Cement Works. Engineers: Locher & Cie.

Fig. 20.—Road Bridge at Eschifofen. Five continuous Prestressed Spans. Maximum span 112 ft. Engineers: E. Schubinger and Weder & Prim.

but they extend, nevertheless, throughout the whole of our knowledge from which our theories are derived. " Theory, Research, and Experience each has the same importance, and form an indivisible unity." [8]

Methods of Design.

In order to calculate the statically-indeterminate forces within the range of permissible stresses the theory of elasticity plays the determining role. It is therefore necessary that reinforced concrete structures, of simple statical form and built in conformity with generally-accepted principles, act mainly as elastic systems.[9] For static loads causing failure and for fatigue, however, the theory of plasticity is valuable. In the elastic range, calculations neglecting the modular ratio may be made when the reinforcement is accurately arranged to follow the lines of principal stress. In the plastic range it is necessary to use a method of calculation without a modular ratio. It is the equilibrium of internal forces that is important.[1]

Buckling is a problem of stability, and not of strength. The method of calculation of stability due to the Swiss Federal Laboratory for Testing Materials also permits the analysis of problems of stability in the plastic range. It gives a

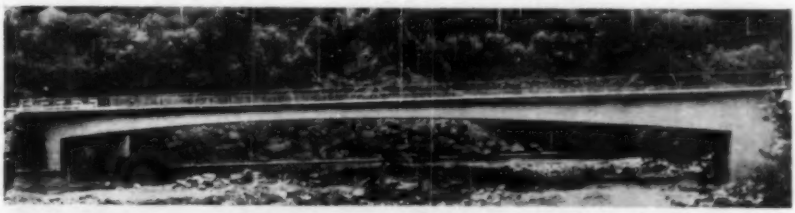


Fig. 21.—Prestressed Road Bridge at Ambri-Piotta. Span 190 ft. Depth at mid-span 3 ft. 9 in. Engineer: W. Krüsu.

Fig. 22.—Prestressed Footbridge at Aarall. Spans 112 ft., 134 ft., 112 ft. Depth at midspan 3 ft. 9 in. Engineer: E. Schubiger.

general solution of Euler's law; for the plastic range the modulus of plasticity is used instead of the modulus of elasticity used in analysis by the elastic theory. The method (known as the LFEM method) is generally applicable to reinforced concrete structures. Tests, measurements of strain, and observations made systematically and with care during twenty-five years on structures well built in reinforced concrete have shown the agreement between theory and practice; practice has at least the same value as theory.[1]

The determination of the internal and external forces on statically-indeterminate structures for the range of permissible stresses may be made on the basis of the theory of elasticity taking account of the modular ratio. There is no justifiable reason for abandoning the theory of elasticity, in spite of the fact that in statically-indeterminate structures there may be a redistribution of forces before failure.[1]

The behaviour of reinforced concrete in the range of permanent (plastic) deformation is being carefully studied in Switzerland.[9] "Experiment is the only source of truth" (Henri Poincaré, "La Science et L'Hypothese," Paris, 1912). Within the range of permissible stresses for reinforced concrete, and still more for prestressed concrete, structures well and carefully built, tests carried out in the laboratory and on actual structures justify the theory of elasticity, and tests show that reinforced concrete structures built in accordance with the best principles are satisfactory in all respects.[1] Reinforced concrete structures, correctly built with concrete resistant to frost and not in permanent contact with water, do not suffer ill effects when submitted to temperatures with annual variations between −20 deg. C. and +25 deg. C. (with daily differences of up to 20 deg. C.), exposed directly to the sun, or to lasting and extreme frost. There is hardly any risk of rusting of the reinforcement if it has been carefully placed,

Fig. 23.—Viaduct at la Praille. Prestressed Continuous Beams 112 ft. long.

if the bars are not too close together, and if they have sufficient cover ($\frac{3}{4}$ in. to $1\frac{1}{4}$ in.) and if concrete containing 650 lb. to 770 lb. of Portland cement per cubic yard has been correctly placed and carefully consolidated over and around the bars.(1)

NOTES.

(1) M. Roš. "Tests and Experiences of Reinforced Concrete Structures in Switzerland." L.F.E.M. Reports. 6 vols. Zürich, 1904 to 1947.

(2) Correct interpretation of theory is necessary to guide us, to prevent us from making errors of principle, and to prevent failures. Theories must make clear the

Fig. 24.—"Shell" Roof Members of 95 ft. span with Prestressed Concrete Ties. Engineer: M. Hossdorf.

principles which are the basis of design and of exact calculations, of the choice of materials of construction, of the organisation of the work, and of the precautions to be taken during construction.

(3) M. Roš. "Beams reinforced with AcTor 40 of 10, 20, and 30 mm. diameter, broken by static loads and by fatigue; bars without hooked ends" (first part), and "The Behaviour of AcTor 40 at high temperatures" (second part). L.F.E.M. Report No. 176. Zürich, 1950. The advantages of steel cold-worked by torsion, the pitch of the helice being equal to or greater than nine times the diameter of the bar, are: Homogeneity of the steel and improvement of its mechanical properties without increasing the carbon content; uniformity of mechanical properties; uniformity of cross section, particularly in deformed bars on which ribs may be produced without sharp corners; a high limit of apparent elasticity; high resistance to fatigue; considerable ductility with respect to static and dynamic loads, which is useful when bars

Fig. 25.—Precast Beams Spanning 55 ft.

Fig. 26.—Prestressed Reservoirs 65 ft. High by 62 ft. Diameter.
Engineer: M. R. Roš.

are to be bent or may be subjected to shock during fabrication; resistance to fracture (in cases of bending and fatigue); a shape such that concrete may be easily placed around it without taking special precautions; high bond strength without the possibilities of concentrations of high stress and without the possibility of splitting the concrete; resistance to temperatures up to 400 deg. C. for a period of four hours unaccompanied by serious deformation.

In order that the steel will resist temperatures up to 400 deg. C. for four hours it is necessary to provide in all reinforced concrete structures a cover of 1 in. to 1¾ in. From the point of view of resistance to fire, cold-twisted steel such as "Elektro-Tor 40" is equal to high-quality bars of type Ac54 and is better than ordinary steel of quality St N. In the case of prestressed concrete it is necessary to take special precautions (cover, efficient bond, provision of sprinkler systems).

(4) The equivalent grip length (without hooks) is $\frac{d}{4}\frac{\sigma_{\text{steel creep}}}{\tau_{\text{bond 0·1 mm.}}}$, where d is the diameter of the bar.

(5) In some abnormal cases—both small and large proportions of steel—it is perhaps desirable to use concrete of quality I with steel of group II, and steel of group III with concrete of quality II. "Festigkeit und Verformung von auf Beigung beanspruchten Eisenbeton-Balken, bewehrt mit 'Torstahl', hochwertigem stahl 'St 52' und Normalstahl 'St N'." "Comparative Study." L.F.E.M. Report No. 141. Zürich, 1942.

(6) M. Roš. "Die materialtechnischen Grundlagen und Probleme des Eisenbetons im Hinblick auf die zukünftige Gestaltung der Stahlbeton-Bauweise." L.F.E.M. Report No. 162. Zürich, 1950.

(7) *Table* III shows the mechanical properties of reinforcement for reinforced and prestressed concrete for the four groups I to IV for Swiss steel. In accordance with the results of tensile tests (ductility, tensile strength, extension, and reduction in area), the coefficient of cold bending, due to Tetmajer, is $K = 50\frac{s}{r} = 100\frac{d}{D}$ (expressed as a percentage), s, d being the thickness of the bar; r and D the radius at which the first crack visible to the eye appears at the extreme tensile side. The value of K corresponds approximately to the extension, particularly the permanent extensions of the most-stressed concrete.

The cold-bending test is made in two ways: (1) without reversal (cracks in the tensile zone), and (2) with reversal, bending and rebending (cracks in compressive zone). In some cases of reversal of bending, particularly repeated reversals, small cracks are formed prematurely in the compressive zone, particularly when deformed bars with ribs are used, because of the type of plastic deformation, cold twisting, brittleness (Bauschinger's effect) and of internal stresses. All these phenomena determine the maximum stresses in cold-twisted bars.

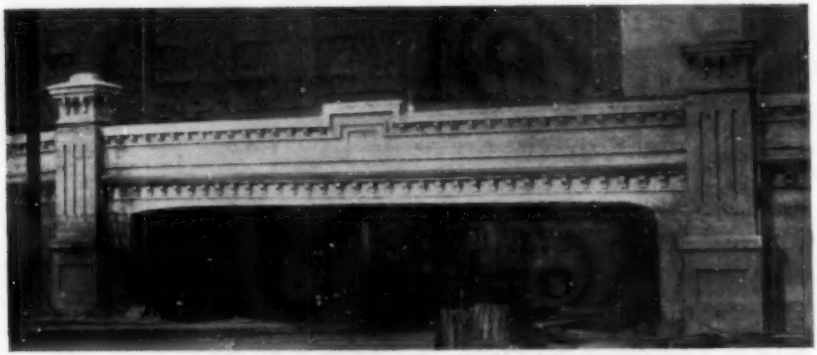
(8) M. Roš. "Significance, Results, and Inter-relationship of Testing Materials based on Experience in Switzerland." Conference of the A.I.G. Liége, 1946.

(9) M. Roš and A. Eichinger. "Uniform method of design of beams in the region of allowable stresses (elastic theory) and of calculating the static loads causing rupture (plastic theory). Establishment of the degree of effective security." Zürich, 1955.

Some Early British Bridges

Glentinnan Viaduct, Scotland. Built in 1905.

Height 90 ft. Nineteen arches of 50-ft. span. Built on a curve on a gradient.



Bridge at Liverpool. Built in 1904.

Span 50 ft. Width 55 ft. between parapets. The deck is 24 in. thick at the ends and 20 in. at the centre.

ITALY

By PROFESSOR GIUSEPPE RINALDI

MINISTERO DEI LAVORI PUBBLICI, ROME.

IN the early days reinforced concrete was not much favoured in Italy, and it was not until after 1910, when the Porcheddu firm of contractors had built the Risorgimento bridge * and the Turin station (on the Hennebique system) that it began to be used for important public works. At this period much research was done by such well-known authorities as Camillo Guidi, Canevazzi, Santarella, and Albenga. Between 1908 and 1911, Neumann, for the first time in Italy, endeavoured to reduce the quantity of concrete and reinforcement by the insertion of lightweight hollow blocks. Between the two world wars, however, the advantages of reinforced concrete resulted in the erection of a number of very daring structures.

Following the second world war the need for quick reconstruction resulted in a great development of reinforced concrete compared with other methods of

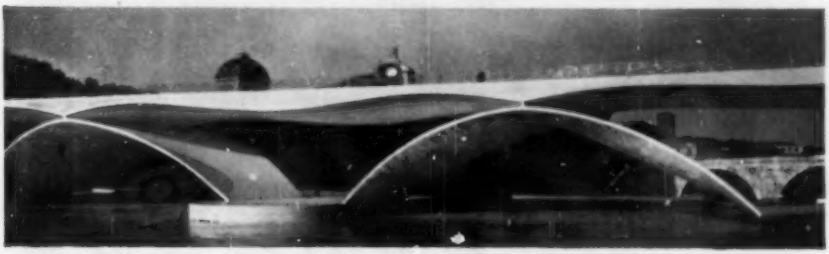


Fig. 1.—A Prestressed Bridge.

building, and some interesting structures were carried out in prestressed concrete. A notable contribution to our knowledge of the composite action of steel and concrete was made in 1938 by Colonnetti, and Cestelli Guidi made the first prestressed precast beams in Italy, using high-tensile steel of 2 mm. diameter made in Sweden. At this period also much research on prestressed concrete was done by Levi, Pizzetti, Castiglia, and Mattiazzo. From 1947 to 1950 theoretical and experimental studies and applications of prestressed concrete were made by Guidi, Morandi, Rainieri, Galli, Sambito, Franciosi, and the writer, and the inventions of Noli and Marioni made possible the erection of interesting and economical floors made with prestressed blocks.

Among those who have contributed to the recent development of concrete particular mention must be made of Professor Pier Luigi Nervi, who has devised a novel method of using a mesh of steel wire (or of bars of small diameter) and a thin covering of high-strength mortar.† In this system the reinforcement follows exactly the shape of the finished structure; it is, in fact, a new material with mechanical characteristics different from those of reinforced concrete, and makes possible the achievement of new architectural forms.

* See page 37.

† See "Concrete and Constructional Engineering", November, 1955.

Among post-war Italian research, mention may be made of that of Professor Levi on the interaction of concrete and steel, on elasto-viscous solids, and the phenomenon of the adaptation of thin slabs.

In 1949 the Italian steel works, at the instigation and on the advice of the writer, started the production of 5-mm. wires of high elastic limit, and in 1954 of 7-mm. wires. With the anchoring and tensioning devices of Morandi, Balducchi, Marozzi, and the writer, Italian engineers have carried out prestressed concrete work in many parts of the world. By making use of the friction between metal surfaces, these systems are among the simplest and most economical for both pretensioning and post-tensioning, and they have made possible simple solutions of various problems, particularly in the economical use of members of novel shapes with external prestressing wires.

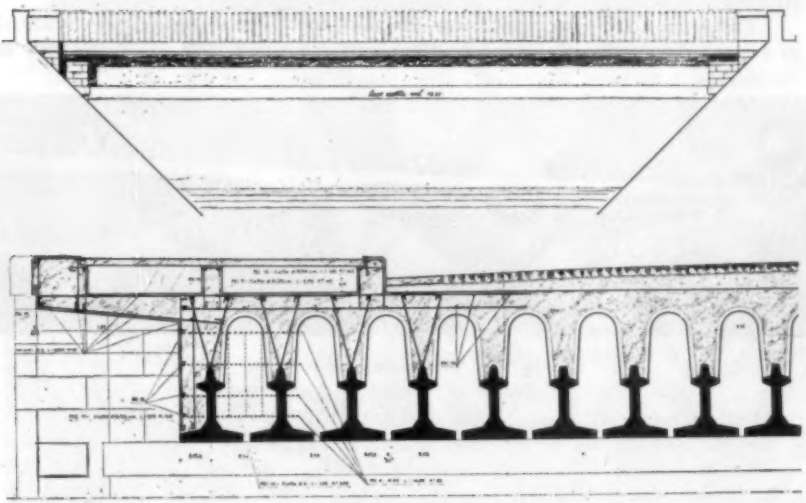


Fig. 2.—Bridge over the River Gironi. Longitudinal and part Transverse Sections.

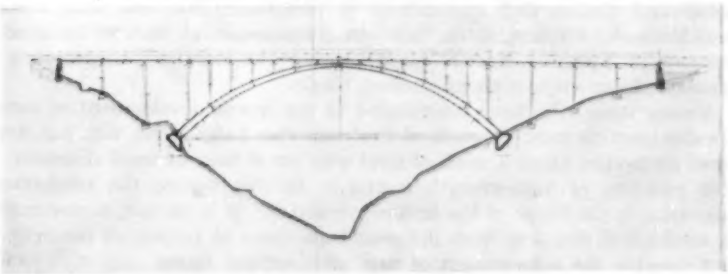


Fig. 3.—Lupara Bridge, Arenzano.

Fig. 4.—Delle Giunture Bridge, over the River Liri.

Distrust of reinforced concrete and prestressed concrete no longer exists in Italy, and both materials are extensively used for bridges, floors, columns, dams, pipes, tanks, maritime structures, special foundations, buildings, silos, tunnels, public works, airport runways, roads and precast members, and the achievements of Italian engineers have achieved world-wide renown. Many of our best engineers have been attracted by the possibilities of prestressed concrete and the slender construction it makes possible.

The following notes and the accompanying illustrations deal briefly with some of the recent achievements of Italian engineers. Some of these structures are of outstanding interest ; others, although small in size, demonstrate ingenious solutions of various problems.

BRIDGES.—One of the most recent works designed by Professor Cestelli Guidi in conjunction with the architect Sr. Zevi, is the bridge shown in *Fig.* 1. The arches and the continuous deck are prestressed and there are hinges between the deck and the crowns of the arches to allow movement due to possible overloading. The bridge over the Gironi river (*Fig.* 2), also designed by Professor Cestelli Guidi, has a simply-supported span of 20 m. (66 ft.). The deck comprises 27 prestressed precast longitudinal concrete beams on the upper flanges of which are dome-shaped precast units which support the in-situ concrete of the deck. It is estimated that this type of hollow construction reduces the weight of the bridge by about half. The precast beams are 52 cm. (21 in.) deep and the total depth of the bridge is 1 m. (39 in.).

Figs. 3 and 4 show two bridges designed by Dr. Riccardo Morandi. The Lupara bridge (*Fig.* 3) is on the new Genoa–Savona motor road. The arch has

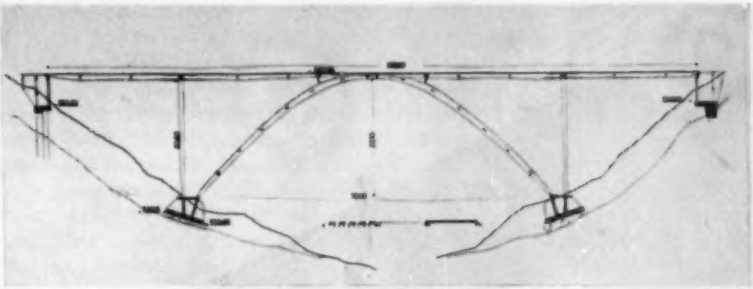


Fig. 5.—Footbridge at Vagli di Sotto.

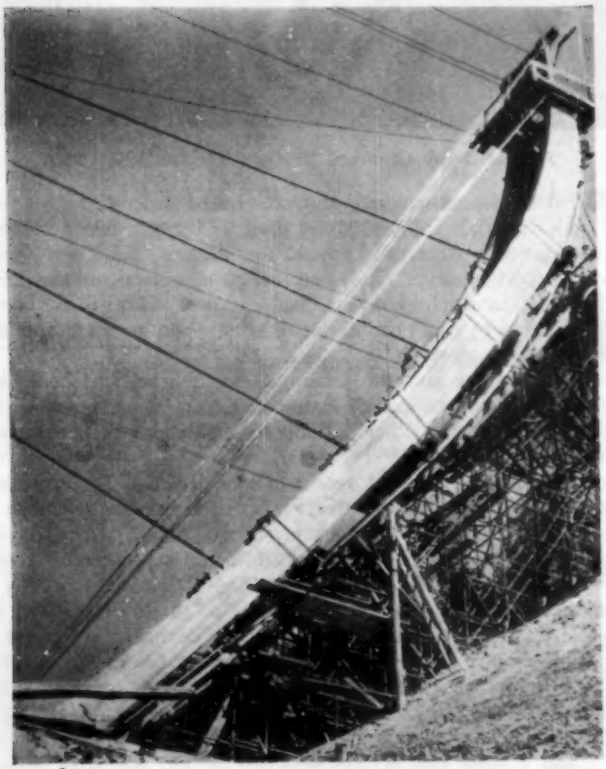


Fig. 6.—Half-arch Ready for Rotating.

a span of 120 m. (400 ft.) and a height of 27·45 m. (90 ft.), and comprises four beams. The Delle Giunture bridge over the river Liri (*Fig.* 4) is 214 ft. long and 23 ft. 8 in. wide, and comprises three prestressed frames fixed at the ends and with slightly arched horizontal members. These frames are carried on foundation blocks on groups of in-situ piles, and comprise the deck slab, thirteen cross beams, and the vertical members. The frames have a span of 203 ft. and a height of 31 ft. 6 in. The upright members vary in width from 5 ft. at the

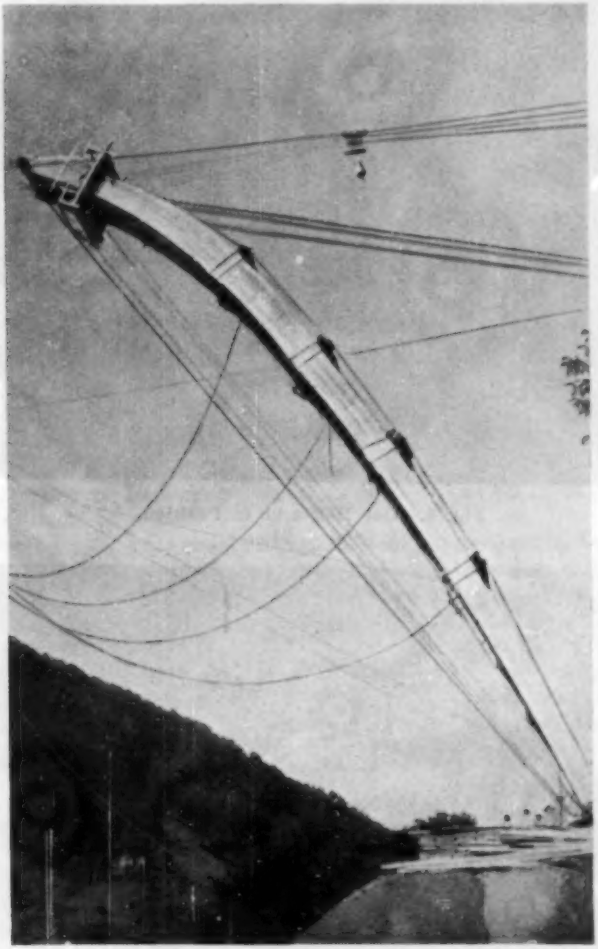


Fig. 7.—Half-arch During Rotation.

footing to 9 ft. at the junction with the beams, and are prestressed with 0·196-in. diameter wires anchored in the foundation. The prestressing cables of the beams were passed through holes drilled in the vertical members. The beams are hollow, and were precast in sections each about 4 ft. 6 in. long. The beams were erected on roller bearings, and the joints were concreted after the shortening due to prestressing and shrinkage had taken place and before the vertical members were prestressed. This was done because of the contraction of a long beam as a result of prestressing, and because it had been noted that the joints between the various sections opened and closed when a bridge deflected under a moving load.

Fig. 8.—One Half-arch in Position.

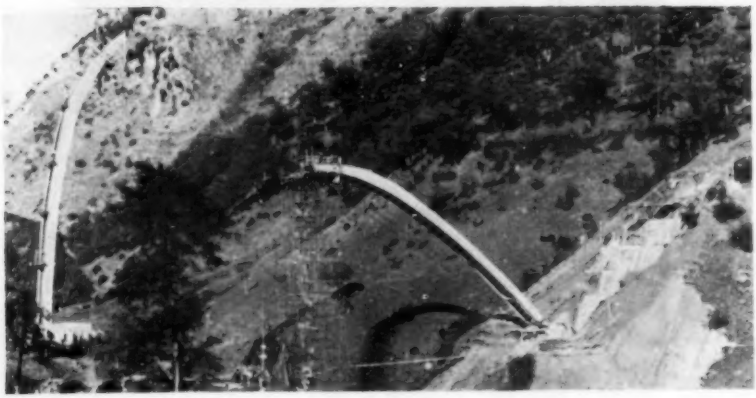


Fig. 9.—Half-arch in Position and the other being lowered.

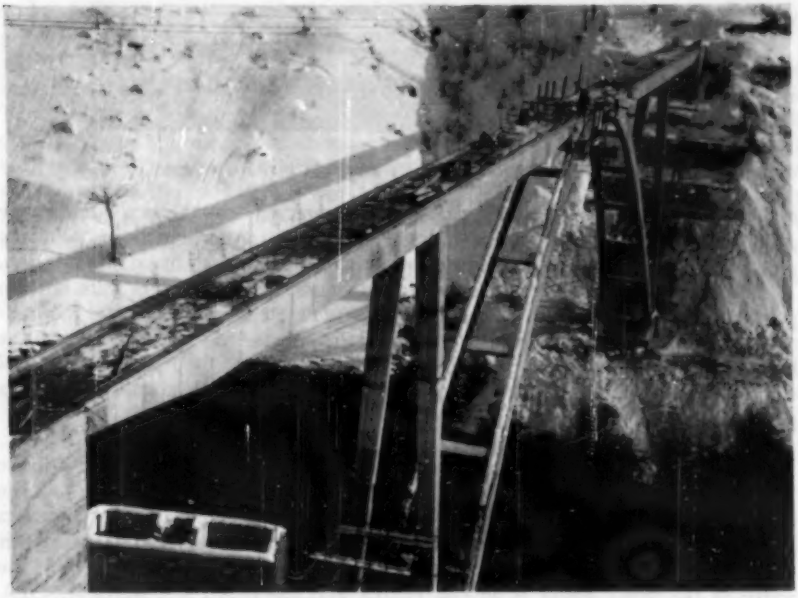


Fig. 10.—Deck under Construction.

Each beam was prestressed with cables containing eighteen wires with an average breaking strength of 256,000 lb. per sq. in. and a yield-point stress of 206,000 lb. per sq. in. The span contains 1·59 cu. ft. of concrete and 7·2 lb. of prestressing steel per square foot of area.

The footbridge (*Figs.* 5 to 10) at Vagli di Sotto was designed by Dr. Riccardo Morandi. It is 420 ft. long by 8 ft. 3 in. wide and comprises a three-hinged arch of 230-ft. span and two continuous beams each of 76-ft. span (*Fig.* 5). The arch is of reinforced concrete and the deck is of prestressed concrete. The deck slabs rest at one end on the abutments, at the quarter-points on two upright members 69 ft. high, and on the crown of the arch. The deck beams are 6¾ in. thick by 4 ft. 2½ in. deep joined by a slab 4¾ in. thick and slender cross-beams. The supporting columns vary in cross section from 1 ft. 8 in. square at the bottom to 3 ft. 4 in. square at the top. The arches are fixed at the footing of the columns and at the crown. The deck beams are formed of precast sections prestressed together.

The arch has a rise of 76 ft., and comprises two ribs connected by cross-beams. All the concrete was made with high-strength cement. Because the great height of the bridge and the nature of the soil would have required expensive staging and shuttering, it was decided to cast the arch in halves against the sides of the mountain and then move them into position (*Figs.* 6 to 9). A central scaffold of steel tubes (*Fig.* 8) was built under the middle of the arch so that each half of the arch could be placed in position separately (*Fig.* 9). To allow

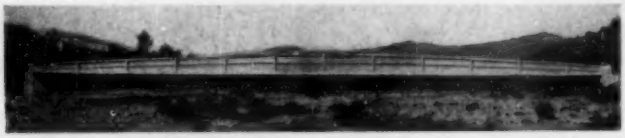


Fig. 11.—A Prestressed Footbridge of 230 ft. span.

for the differing stresses as the half-arch was erected, prestressing cables were provided at the intrados and extrados by which compressive stresses could be produced as required according to the position of the half-arch during its rotation. The raising of each half-arch occupied eight hours, and when they were both in position (*Fig.* 10) the hinge at the crown was concreted. At this stage the half-arches acted as curved inclined beams simply supported at each end, and twelve hours after the crown was grouted it was lowered so as to produce horizontal compression in the arch. The bridge is designed to withstand a gale of 75 miles per hour.

The bridges shown in *Figs.* 11 to 15 were designed by the writer.

The prestressed footbridge shown in *Fig.* 11 is a single prestressed I-shape beam of 70 m. (230 ft.) span. The depth varies from 1·1 m. (3 ft. 7 in.) at the bearings to 2·5 m. (8 ft. 2 in.) at the centre and there are triangular brackets at 6-m. (20-ft.) intervals. It is thought that this is the longest beam of this type so far built in the world. The thickness of the web is 16 cm. (6¼ in.), the width of the upper flange is 18 cm. (7 in.), and the depth is 1 m. (3 ft. 3 in.). The weight is about 140 tons. The load is deemed to be evenly distributed at the rate of 400 kg. per sq. m. (82 lb. per sq. ft.). There are 34 cables containing 5-mm. wires, which produce a total compression of 700 tons. Wind pressure of

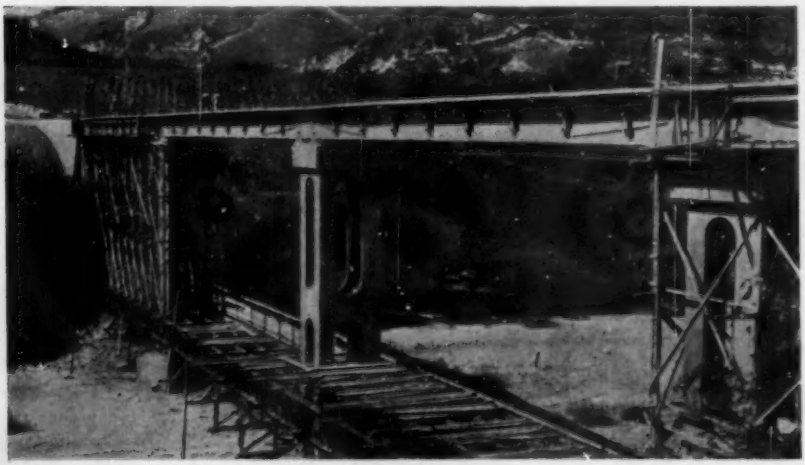


Fig. 12.—Bridge at Filetto.

90 kg. per sq. m. (18 lb. per sq. ft.) is resisted by two cables each with twelve 5-mm. wires.

The prestressed bridge (*Fig.* 12) over the Santerno at Filetto di Fontanelice comprises four simply-supported spans. The total length is 111 m. (364 ft.). The roadway is 3 m. (10 ft.) wide and there are two cantilevered footpaths each 0·75 m. (2 ft. 6 in.) wide. Each span comprises four prestressed beams (*Fig.* 13) with a span of 26 m. (85 ft.) between the centres of the bearings, connected by ten transverse beams 20 cm. (8 in.) deep. Each beam is prestressed by twelve cables of twelve 5-mm. (0·2-in.) diameter wires arranged for half their length inside the lower flange and for the other half outside the web. The beams were made in one wooden mould lined with sheet metal. After concreting the slab,

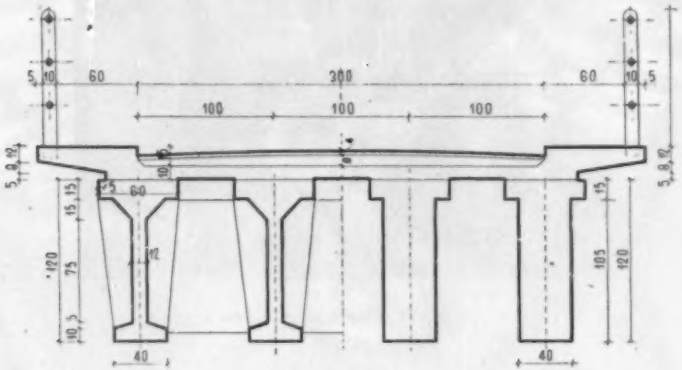


Fig. 13.—Bridge at Filetto.

all the transverse cables were tensioned and the longitudinal cables were further tensioned to the final stress of 100 kg. per sq. mm. (142,000 lb. per sq. in.). The loss of tension in the period is estimated to have been 15 kg. per sq. mm. (22,400 lb. per sq. in.). The internal cables were grouted and the external cables were gunited on the outside and then grouted.

The bridge (*Figs.* 14 and 15) over the Castenaso at Idice had to carry heavy traffic and to avoid causing dangerous currents at a sharp bend in the river. It is a beam-and-slab structure with a span of 36 m. (118 ft.) and 11 m. (36 ft.) wide, with one end fixed and the other on a roller bearing. There are nine I-section longitudinal beams; the upper flanges are 95 cm. (3 ft. 2 in.) wide and 18 cm. (7 in.) deep, the web is 12 cm. (4¾ in.) wide, and the lower flange 40 cm. (16 in.) wide and 20 cm. (8 in.) thick. The overall depth of the beams is 1·7 m. (5 ft. 7 in.). The longitudinal beams are connected by nine cross-beams 1·5 m. (5 ft.) deep and 20 cm. (8 in.) wide which, together with the slabs, are prestressed transversely. Each beam was prestressed with 1200 kg. (2640 lb.) of high-tensile steel comprised in eighteen cables of twelve 5-mm. diameter wires, and also contains 530 kg. (1160 lb.) of mild steel stirrups. The transverse beams are prestressed with four cables containing twelve 5-mm. wires, and there are three cables in the slab between each pair of beams. The cables are bound with

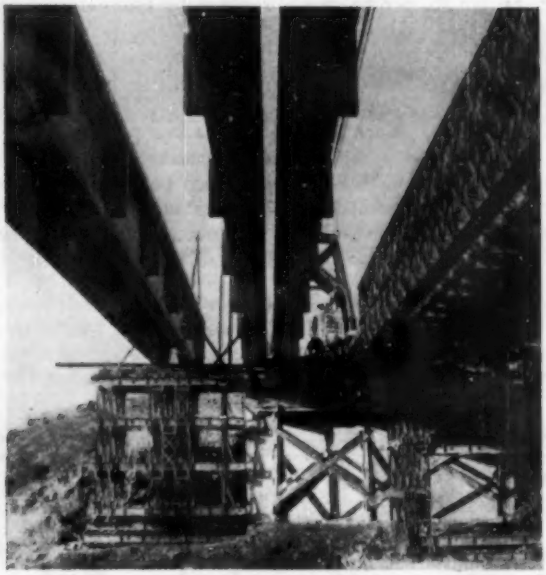


Fig. 14.—Bridge at Idice.

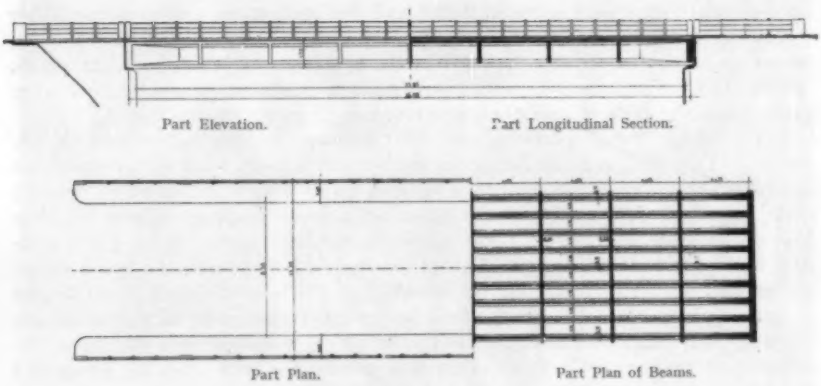


Fig. 15.—Bridge at Idice.

steel helices within the metal sheaths, and grouted. The concrete had a compressive strength of not less than 400 kg. per sq. cm. (5700 lb. per sq. in.). The cables were tensioned from both ends, twelve wires at a time.

BUILDINGS.—As some of Professor Nervi's work was illustrated in this journal for November, 1955, only two further illustrations of his notable achievements are illustrated here. *Fig.* 16 is the roof of the main hall of the Turin Exhibition building. This consists of precast reinforced concrete trough-shaped elements fitted with glazing and closed at their ends with connecting diaphragms. Reinforced concrete ribs in the troughs form the bearing structure. A wool factory in Rome is shown in *Fig.* 17. The floor is of the flat-slab type, and the

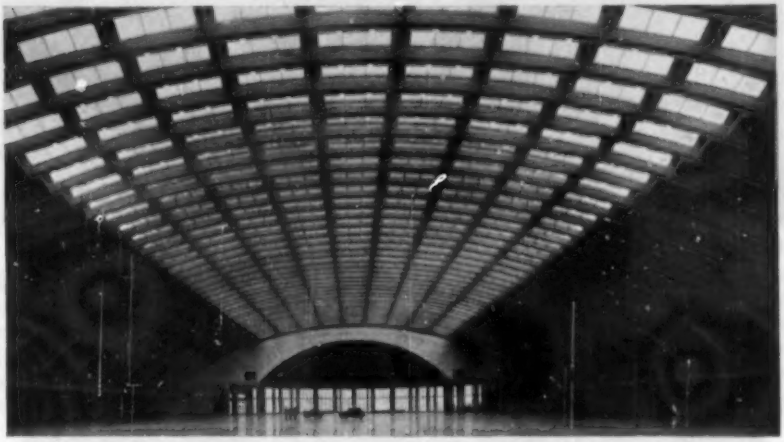


Fig. 16.—Main Hall, Turin Exhibition Building.

curved ribs are arranged to coincide with the principal stresses; it was built on movable shutters.

The garage at Turin, designed by Professor Franco Levi and shown in *Fig.* 18, has a vaulted roof prestressed in both directions. A dome with prestressed ribs (*Fig.* 19) at the new Stock Exchange building at Turin, also designed by Professor Levi, has a base 40 m. (132 ft.) square.

The Pio Palace (*Figs.* 20 and 21) in Rome, designed by Professor Marcello Piacentini, includes offices, a hostel, and a concert hall with seating accommodation for 2000 people. The dome is of semi-elliptical shape and measures in plan 32 m. by 30 m. (105 ft. by 100 ft.).

The goods-handling and warehouse building at Trieste (*Figs.* 22 and 23) comprises three stories. The top floor is used for the storage of goods which the dock regulations do not permit to remain on the two lower floors, and so avoids the need to take such goods to other stores. The top floor is also accessible by the cranes on the wharf. The buildings cover an area of about 38,000 sq. m. (410,000 sq. ft.). The reinforced concrete frames are carried on beams resting on in-situ piles 15 m. (50 ft.) long with a bearing capacity of 70 tons.

Fig. 17.—A Factory in Rome.

Fig. 18.—Garage at Turin.

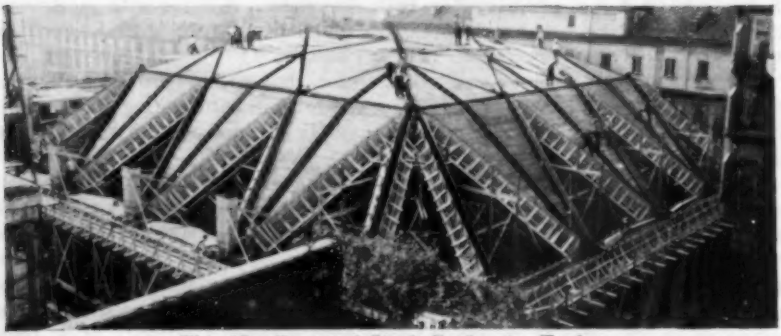


Fig. 19.—Dome of Stock Exchange, Turin.

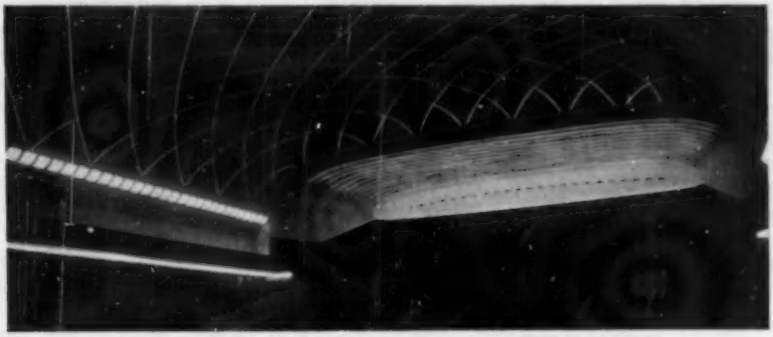


Fig. 20.—The Pio Palace, Rome: View from Stage.

The distance between the centres of the frames is 9·9 m. and 8·3 m. (32 ft. and 27 ft.) on the ground and first floors and 17 m. and 9·9 m. (56 ft. and 32 ft.) on the top floor. The floors are designed for a load of 1500 kg. per sq. m. (306 lb. per sq. ft.) plus a dynamic load of 25 per cent. The engineer is Dr. Renzo Colautti.

The structure shown in *Figs.* 24 and 25, designed by the writer, is partly in reinforced concrete and partly prestressed. The site overlooks one of the most interesting panoramas of the Bologna Appenines. It consists of a massive column supporting a beacon and a clock, and a terrace, with an area of 80 sq. m. (860 sq. ft.) and in the shape of a sector of a circle, overhanging the cliff. The supporting column is embedded in the rock, its rear face being prestressed. On the front face two brackets support the terrace, while at the back a part of the

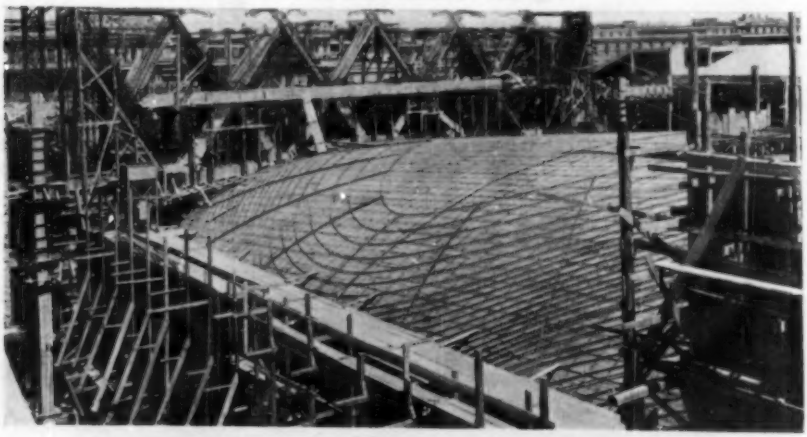


Fig. 21.—The Pio Palace, Rome: Dome During Construction.

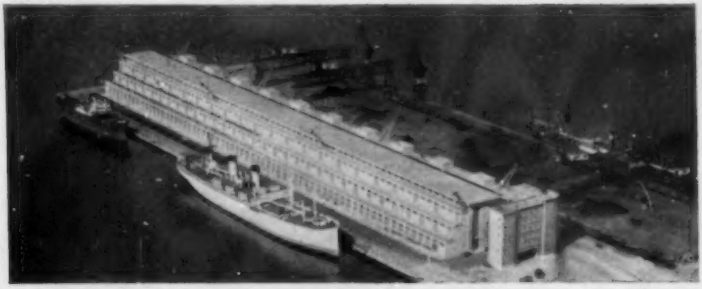


Fig. 22.—Transit Shed at Trieste.

Fig. 23.—Transit Shed at Trieste.

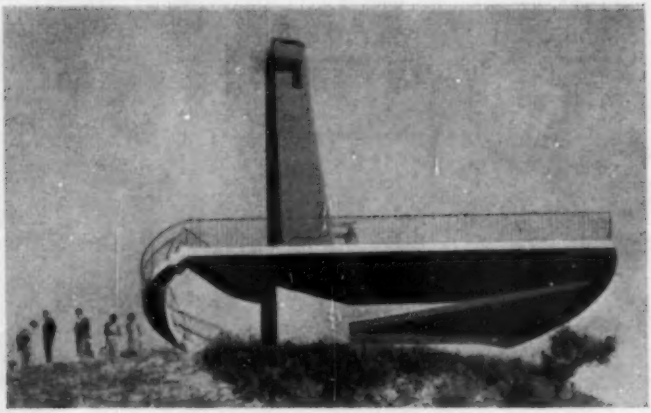


Fig. 24.—An Observation Terrace.

terrace is reached by a helical staircase in prestressed concrete without side supports. The staircase has precast steps and is prestressed with three cables each containing twelve 5-mm. dia. wires tensioned to 33 kg. per sq. mm. (47,000 lb. per sq. in.). The maximum stress in the concrete is 45 kg. per sq. cm. (640 lb. per sq. in.) and in the steel 1000 kg. per sq. cm. (14,200 lb. per sq. in.).

The prestressed staircase (*Fig.* 26), also designed by the writer, has precast treads. The height of the helix is 4 m. (13 ft.) and the diameter of the circumference, in horizontal projection, 2·1 m. (6 ft. 11 in.); it is hinged at the bottom and fixed at the top. In all the steps holes are formed for the prestressing wires. The three prestressing cables, each comprising twelve wires of 5 mm. (0·2 in.) diameter, are fixed at the ends with anchors of the friction type, and are tensioned to 33 kg. per sq. mm. (47,000 lb. per sq. in.); the total prestressing force is 23 tons.

The garage at Florence (*Fig.* 27), designed by Dr. Riccardo Morandi, has a floor area of about 3500 sq. m. (37,500 sq. ft.). The roof is supported by eleven

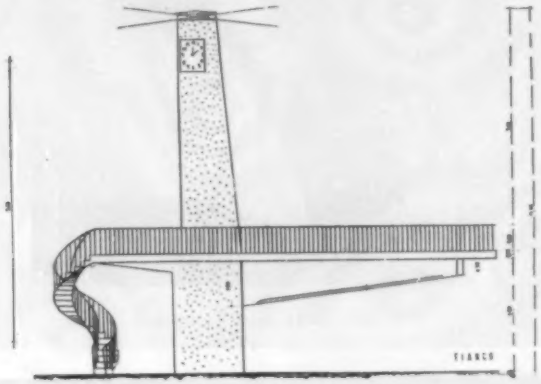


Fig. 25.—An Observation Terrace.

statically-indeterminate frames of prestressed concrete. The structure is built entirely of precast elements with the exception of the foundation plinths and some of the columns. The concrete had a minimum compressive strength of 6420 lb. per square inch. The prestressing steel had a maximum strength of 150,000 lb. per sq. in. Some of the quantities of materials per square foot of floor area are: Concrete, 0·5 cu. ft.; high-tensile steel, 0·82 lb.; mild steel, 1·54 lb.

The two-story building at Colleferro, also designed by Dr. Morandi, has a floor area of 5700 sq. m. (59,000 sq. ft.), and is notable for its large prestressed concrete frames (*Figs.* 28 to 30) and for the extensive use of precast elements. The lower floor (*Fig.* 29) consists of reinforced concrete slabs and beams supported by Y-shaped columns in order to increase the spacing to 33 ft. The upper story (*Fig.* 30) comprises fourteen prestressed frames spaced 5 m. (16 ft. 6 in.) apart. The columns were cast in situ and the beams are formed of precast blocks prestressed together. The columns are 16 ft. 6 in. high and have a maximum width of 5 ft. 3 in.; the beams are I-shape, and vary in depth from 6 ft. to 7 ft. 10 in.

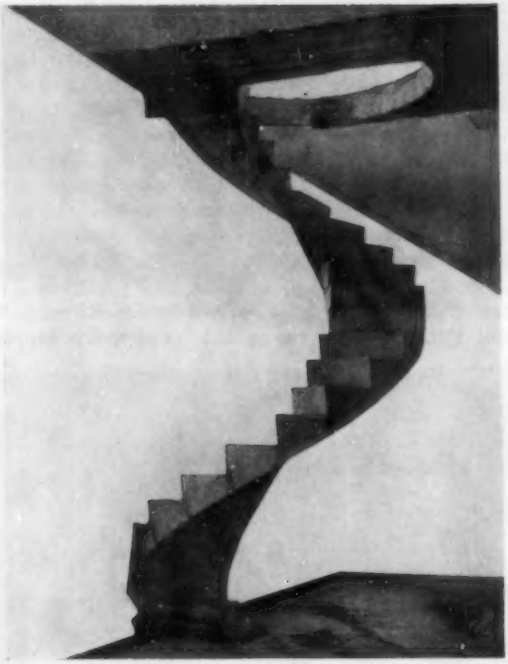


Fig. 26.—A Helical Staircase.

Fig. 27.—Garage at Florence.

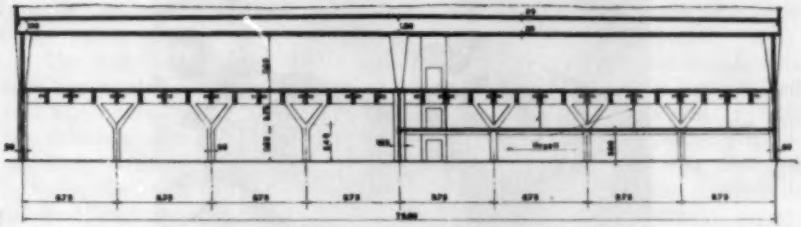


Fig. 28.—Factory at Colleferro: Transverse Section.

Fig. 29.—Factory at Colleferro: Ground Floor.

Fig. 30.—Factory at Colleferro: Upper Floor.

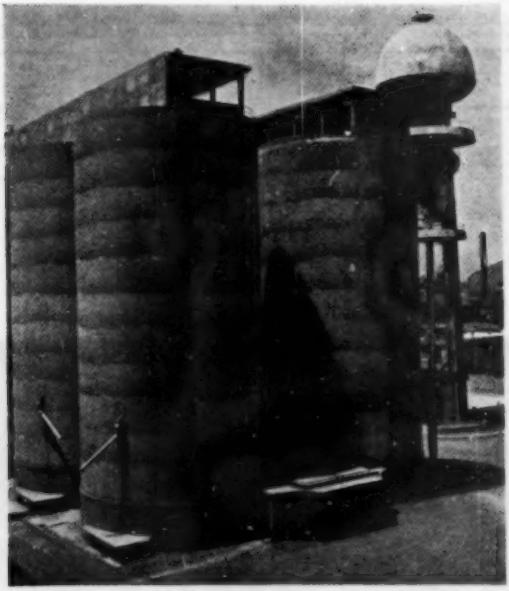


Fig. 31.—Prestressed Silos before Guniting.

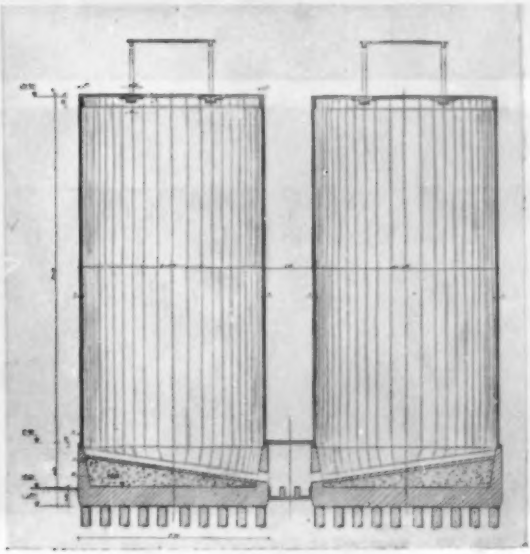


Fig. 32.—Prestressed Cement Silos.

Initially the beam could slide freely on a roller hinge, but the ends were fixed to the columns after the beams had been shortened by the prestress.

The design of a group of eight prestressed cement silos on piled foundations near Naples, designed by Professor Giuseppe Sambito, is shown in *Figs.* 31 and 32. The internal diameter is 11·4 m. (37 ft.) and the height 22·2 m. (73 ft.). The thickness of the wall is 15 cm. (6 in.). The walls were prestressed circumferentially with high-tensile wire of 4-mm. diameter. The wire was arranged helically, the pitch of the helice being related to the pressure of the contents at different heights. The roof is carried on shallow prestressed beams.

The plan of the garage shown in *Figs.* 33 and 34, designed by Palazzuoli Bevilacqua, enables vehicles to be moved rapidly. The central portion with a skylight and ventilator is used for repairing and cleaning. The roof comprises a central dome and a cantilever; the circular girder is 23 m. (76 ft.) diameter and is supported by eight columns arranged in pairs. The foundations, columns, the girder supporting the dome, and the dome are of reinforced concrete, and the cantilevered part is in-filled with hollow clay blocks. The columns are 60 cm. (2 ft.) square, and the circular girder has a cross section of 0·6 m. by 1·2 m. (2 ft. by 3 ft. 11 in.), increased to 0·6 m. by 2 m. (2 ft. by 6 ft. 7 in.) at the supports. The dome is 8 cm. ($3\frac{1}{8}$ in.) thick. The cantilever is 14·5 m. (48 ft.) wide and 10 cm. (4 in.) thick, of which the blocks are 8 cm. ($3\frac{1}{8}$ in.) thick and the concrete topping is 2 cm. ($\frac{3}{4}$ in.) thick. The floor slopes to the centre where washing-water is collected. Rainwater is discharged through pipes in the columns. The dome was designed as a " shell ". The part of the roof in the form of a truncated

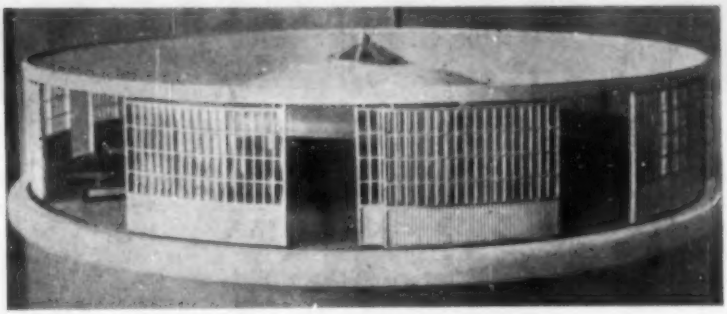


Fig. 33.—A Circular Garage.

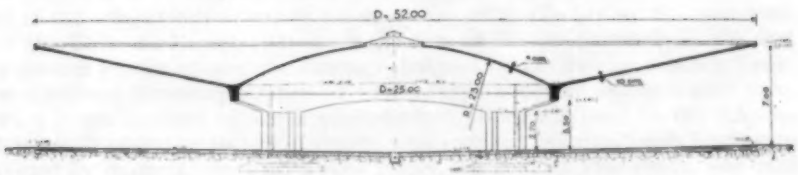


Fig. 34.—Cross Section of Garage shown in Fig. 33.

Fig. 35.—Bridge at Viterbo: Span 300 ft.

cone with cantilever was designed as the bottom of an Intze tank. The centering for the dome was removed eight days after concreting, and after twenty days in the case of the beam and cantilever. The centering for the cantilever was removed from sectors, starting at the circular girder and proceeding towards the edge of the slab. After removing the centering there was a deflection at the edge of the cantilever of about 4 cm. (1½ in.). The work was completed in 120 days.

The bridge at Viterbo, shown in *Fig.* 35, was designed by the writer.

BELGIUM

By F. R. RIESSAUW

Professor of Reinforced Concrete at the University of Ghent.

It is difficult to fix exactly the origin of the process of reinforcing building materials, for even the Romans used a combination of iron and masonry. In Belgium, construction in reinforced concrete was started by François Hennebique, who in 1892 actively publicised his processes and invited architects and engineers to visit his precast paving flag factory in Brussels, where he made tests and experiments. In 1899, Paul Christophe issued an important work describing in detail the numerous structures built by Hennebique. In 1890, under the supervision of General Brialmont, plain concrete was used for forts on the river Meuse. In 1891 the firm of Blaton–Aubert constructed plain concrete sewers at Malines, and in 1892, under the direction of a commission which relied largely on the studies of the engineer Jules Zone, the same firm built a large reinforced concrete main sewer in Brussels. In 1894 the State Railway built the roofs of a Home of Rest at Chimay in reinforced concrete, including beams having a span of 5 m. (16 ft. 6 in.).

Fig. 1.—Warehouse at Brussels. Built about 1900.

In 1896, in his important work " La construction architecturale en fer, fonte et acier ", which had been awarded first prize in the King's competition, Vierendeel (Professor at the University of Louvain) included designs in reinforced concrete, and it seems that this was the first Belgian work on the subject ; the examples and tests mentioned, however, are little related to reinforced concrete as we know it to-day.

In 1896, Hennebique's system was widely used at the Palace of Justice at Verviers, including the frame, the floors, and large square columns with brackets. In 1897, also at Verviers, floors with spans varying from 5 m. to 8·7 m. (16 ft. 6 in. to 28 ft.), subjected to a load of 350 kg. per sq. m. (72 lb. per sq. ft.), were used at the École de Musique. In 1897 the firm of Blaton–Aubert built the first important reinforced concrete structure designed by the Belgian engineer Casse, who followed Hennebique's method. Hennebique's method was used until 1900, when it was replaced by Christophe's method, which was used for the S.A. des Lampes Washington factory, Brussels, and included beam-and-slab floors supported by columns. In 1899 a skew bridge, the Pont du Pain Perdu, was built over the river Lys at Ghent ; the bridge was designed to have the appearance

of masonry. The arch had a span of 22 m. (72 ft.) and comprised eight beams 40 cm. (16 in.) deep at the crown and 2 m. (6 ft. 6 in.) deep at the supports and a slab 14 cm. (5½ in.) thick.

The most important event in the evolution of reinforced concrete was the publication in 1899, in Annales des Travaux Publics, of the remarkable report, " Le Béton Armé et ses Applications ", of Paul Christophe, Engineer of Bridges and Roads. This work was the result of studies made by him, in collaboration with Hennebique, of reinforced concrete structures built in Paris for the exposition of 1900. The report describes in great detail each application of reinforced concrete. The chapter devoted to the theory of reinforced concrete presents some remarkable scientific analyses and a sound and simple method of designing beams ; this was the forerunner of the method of design commonly used to-day. The method could be used by any engineer, and was free from the restraints imposed by some of the proprietary methods then in use.

About 1900 the Société Louis De Waels acquired the Hennebique patent in Belgium, and built a warehouse in Brussels (*Fig.* 1) designed by Jules Zone, who carried out other reinforced concrete work at Brussels, notably the dock walls of the Vergote basin and adjoining basins, as well as several maritime buildings. Another talented engineer who was influential in the development of reinforced concrete in Belgium was Dumas. With Perraud, he organised a consulting office in which many important structures were designed. He produced a new system of reinforcing, with numerous sloping steel bands forming the core of a beam, so avoiding the use of inclined bars and stirrups ; this system was used by Entreprises Monnoyer in all the structures at the Saint Sauveur dock in Brussels.

In 1904, Prax designed the elegant Mativa footbridge (*Fig.* 2), 80 m. (260 ft.) long, over the river Ourthe at Liége ; it has two approach spans and a central span of 55 m. (180 ft.) with a depth at the crown of 35 cm. (14 in.). The foundations were constructed by the Compressol system. This bridge is still in service. Léon Cosyn also took an important part in the development of reinforced concrete. He was the principal architect of the Belgian Railway Administration, but devoted

Fig. 2.—Footbridge at Liége. Built in 1904.

Fig. 3.—Precast Water Tower. Built in 1906.

most of his time to engineering, including many reinforced concrete structures, and published " Traité Pratique des Constructions en Béton Armé " (1911) and " Exemples de Calcule de Constructions en Béton Armé " (1914).

In 1906 precast elements were used, and *Fig.* 3 shows a precast water tower built at this time. Many towers and chimneys have been built by this system by the firm of Monnoyer. In northern Belgium many structures have piled foundations, and in 1896 Hennebique introduced a precast square pile. Early in this century several Belgian firms used circular piles cast in metal forms. Later, and mainly in the foundation of the viaduct of the North-South junction of the boulevard du Midi in Brussels, octagonal piles with spiral reinforcement, of the Considère type and capable of supporting very heavy loads, were used. The Compressol system uses mechanical compression of the soil and allows the concrete to fall freely into position ; this system has given excellent results in certain soils ; no metal lining is used. The Franki pile, a Belgian invention, is now used throughout the world ; this pile was invented in 1909 by Frankignoul.

Between the two wars many important industrial structures were built in Belgium, notably the works for Ougrée-Marihay and John Cockerill at Liége, comprising coke ovens, silos, ore bins (*Fig.* 4), and towers. Many power stations were also built.

In Belgium, bridges must generally be as low as possible while allowing sufficient clearance over rivers, railways, or roads ; also, work at the site must be kept to a minimum. In most of the cases the bearing capacity of the soil is poor, with the result that it is easy to make an adequate foundation for vertical loads but difficult and expensive to provide for horizontal loads. The Heer-Agimont bridge over the river Meuse comprises two large beams joined by transverse beams that carry the deck. Each beam, of varying depth, is continuous on four supports, and the hand-rail, of a strong triangular shape, was taken into account as stiffening the structure. There are three spans of 53·75 m. (175 ft.), 55·5 m. (180 ft.), and 31·75 m. (103 ft.). Several beautiful concrete bridges were built during the construction of the Albert canal, including those at Gellinck (*Fig.* 5) and Vroenhoven.

A very important construction in Brussels is the North-South junction, linking the railways to the north and south. This work, started before the first war, was resumed in 1936. It includes a viaduct 900 m. (3000 ft.) long built before 1914, a tunnel 1920 m. (6300 ft.) long and 35 m. (115 ft.) wide started in 1936, and a viaduct 200 m. (655 ft.) long. The viaducts are of steel frame construction. The tunnel is of reinforced concrete, with a steel frame, and comprises a great number of small beams. Above the tunnel is a space 3 m. (10 ft.) high which may be used as a garage or an air-raid shelter.

The Kruisschans lock at Antwerp was built after the first world war. The base is covered with reinforced concrete 2 m. (6 ft. 6 in.) thick, perforated with openings of 20 cm. (8 in.) diameter which are filled with gravel and serve to reduce

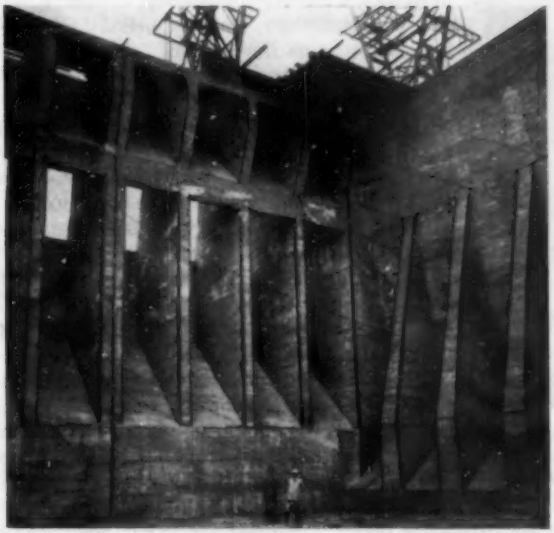


Fig. 4.—Ore Bin at Ougrée-Marihay.

Fig. 5.—Gellinck Bridge over the Albert Canal.

the water pressure under the slab. This makes it impossible to empty the lock, so sliding gates are provided which can be opened to release the water. Each chamber is 41 m. (132 ft.) long and 8 m. (26 ft.) wide at the entrance and 10 m. (33 ft.) wide for most of its length. The greatest length of the lock that can be used for the passage of ships is 270 m. (900 ft.).

One of the tunnels under the river Escaut is for vehicles and the other for pedestrians. The tunnel for vehicles (*Fig.* 6) is 2100 m. (7000 ft.) long, 6·75 m. (22 ft.) wide at the bottom, and 4·5 m. (14 ft. 9 in.) high. The walls are of reinforced concrete. The approaches are connected by a cast iron tube 1235 m. (4000 ft.) long. The exterior diameter of the lining is 9·4 m. (31 ft.), the thickness of the arch is 35 cm. (14 in.), and the width of the rings 0·672 m. (26 in.).

Fig. 6.—Tunnel under the River Escaut, Antwerp.

The arches are lined on the interior with concrete. The tunnel for pedestrians and cyclists is a cast iron tube between reinforced concrete approaches; this tunnel has an interior diameter of 4·3 m. (14 ft.) and an external diameter of 4·75 m. (15 ft. 6 in.), and is 575 m. (1900 ft.) long.

A little before the second world war a large dam (*Fig.* 7) was started on the Vesdre river at Eupen and was finished after the war. The dam is of the gravity type, and enabled the level of the river to be increased by 56·75 m. (186 ft.). It has a radius of 375 m. (1250 ft.) and an arc length of 350 m. (1160 ft.). The top is 8 m. (26 ft.) wide with a partly cantilevered roadway 11 m. (36 ft.) wide including footpaths. The maximum thickness of the base is 55 m. (180 ft.) and the upstream face has a slope of 1 : 80. The drainage of the upper side is by flumes connecting a longitudinal gallery under the roadway to a gallery just above

Fig. 7.—Dam on the River Vesdre at Eupen.

the foundation ; the diameter of these flumes varies from 0·8 m. (32 in.) to 0·3 m. (12 in.), and they are 3·75 m. (12 ft. 6 in.) apart.

The circular hangars (*Fig.* 8) at Grimbergen-lez-Brussels were built, according to the design of M. Hardy de Quiévrain, for private aircraft, and have a capacity of 36 aeroplanes. The floor area is 2000 sq. m. (21,500 sq. ft.). The flat-slab type of roof has an external diameter of 50 m. (165 ft.) and a maximum height of 7 m. (23 ft.). The cantilever surrounding the central dome is 22 m. (72 ft.) diameter. The structure is supported on only four columns placed at the intersection of the dome and the cantilever. The least thickness of the roof varies from 0·08 m. (3¼ in.) in the dome to 0·12 m. (4¾ in.) in the cantilever part. The reinforcement comprises concentric rings and radial bars.

A few weeks ago the new Baudouin lock (*Fig.* 9) at Antwerp was opened for service ; this will relieve the Kruisschans lock, and has a length of 360 m. (1200 ft.), a width of 45 m. (150 ft.), and a depth of 10·5 m. (34 ft.).

From 1900, under the influence of Paul Christophe, the Administration des Ponts et Chausées recommended methods of calculation, and the first code for reinforced concrete was published in 1923 under the auspices of the Belgian Association of Standardisation. In 1920 the Association issued " Instructions relatives aux ouvrages en béton armé ", which imposed some restrictions on the

Fig. 8.—Hangar at Grimbergen.

applications of reinforced concrete but did not impede the progress of the material. Belgian standards have since been frequently revised, and the latest (the fifth) edition was issued in June last by the Association, which is now known as L'Institut Belge de Normalisation.

The first laboratory capable of conducting tests on concrete was at the arsenal of Malines, where in 1913 Professor Rabozée, of l'École Royale Militaire, equipped his laboratory for testing cement and concrete. In 1926, Professor Magnel created in Ghent his Laboratoire du Béton Armé, and this has for nearly thirty years contributed to the development of concrete. This laboratory, first housed in an annex of the Belgian Railroads, was transferred in 1930 to the University of Ghent.

Since the introduction of prestressed concrete Belgium has played a leading role in its application. The first application, during the second world war, used the Blaton–Magnel system of pre-tensioned steel wires in the construction of the

Fig. 9.—Baudouin Lock, Antwerp.

rue du Miroir bridge at Brussels, with a span of 66 ft. and a width of 12 ft. The working stresses were 2150 lb. per square inch in the concrete and 120,000 lb. per square inch in the steel. The thickness is 3 ft. 9 in. at midspan and 3 ft. 7 in. at the supports. The slab was prestressed by means of 29 cables each comprising 56 wires of 5 mm. (0·197 in.) diameter. Half of the cables had more curvature than the others to obtain uniform compression at the end of the slab.

After two or three smaller applications of prestressed concrete the De Smet bridge (*Fig.* 10) was built in 1947. This is a road bridge with a span of 28·8 m. (95 ft.) carrying a road 12 m. (39 ft. 4 in.) wide and two footpaths each 3 m. (9 ft. 10 in.). The road carries a tramway. The total thickness of the beam and road surface is 1·19 m. (3 ft. 11 in.). The deck comprises prestressed concrete I-beams cast on the river bank. The flanges of the beam are 51·5 cm. (20 in.) wide, the web is 17·5 cm. (7 in.) thick, and the total depth is 1·22 m. (44 in.). Each beam is prestressed by three cables, one containing 48 wires of 7 mm. diameter and two containing 24 wires of 7 mm. diameter. The prestress was established by tensioning the wires up to 92 kg. per sq. mm. (135,000 lb. per sq. in.). In order that

Fig. 10.—De Smet Bridge, Ghent.

several beams shall act together under the loads from the tramcars and other vehicles, a transverse prestress was provided.

The first important statically-indeterminate bridges were the continuous girder bridges at Sclayn and Dinant (*Figs.* 11 and 12). The Sclayn bridge is a continuous-girder structure of two 206-ft. spans and was fully described in this journal for June, 1950. Many bridges using the Freyssinet system of prestressing have been built over the new Nimy–Blaton canal (*Fig.* 13). These bridges are composed of I-beams of varying depth. The beams rest on struts hinged at both ends; the interior struts are in compression and the exterior struts are in tension. The deck is not fixed at the ends, but is stable because any tendency to displace the bridge longitudinally would create bending in the beams that would oppose the deformation. The extrados of the beam follows the profile of the road; in some bridges the extrados is a circular arc of large diameter; in other bridges it has a slight inclination. Each beam is of I-section 1·50 m. (5 ft.) deep at mid-span, 2·5 m. (8 ft. 3 in.) deep at the interior hinges, and 0·8 m. (32 in.) deep at the exterior hinges. The upper flange is 1·5 m. (5 ft.) wide and 16 cm. (6½ in.) thick, and the lower flange 44 cm. (17½ in.) wide and 18 cm. (7 in.) thick. The flanges are connected to the web with circular diaphragms of large diameter, thus facilitating the placing of the concrete. The thickness of the web is 16 cm. (6½ in.) at midspan and 20 cm. (8 in.) at the interior hinges. The beams were prestressed with cables of twelve 5-mm. wires.

Other important prestressed bridges are two road bridges on the canal near Ghent (*Fig.* 14). These bridges are statically-indeterminate with three spans

Fig. 11.—Sclayn Bridge over the River Meuse.

Fig. 12.—Prestressed Bridge over the Meuse at Dinant.

Fig. 13.—Bridge over the Nimy-Blaton Canal.

Fig. 14.—Prestressed Road Bridge near Ghent.

Fig. 15.—Prestressed Hangar at Melsbroeck.

of 26 m., 52 m., and 26 m. (85 ft., 170 ft., and 85 ft.). They are on a skew and the superstructure is monolithic. The total width is 20 m. (65 ft.). There are eleven main continuous I-beams at 1·75 m. (5 ft. 9 in.) centres. The depth of the beams varies from 2·7 m. (9 ft.) at the piers to 1·5 m. (5 ft.) at mid-span and the supports. The cables are placed externally and there is no transverse prestressing. The diaphragms are in reinforced concrete. The piers are on piles. Above the pier is a bearing wall 35 cm. (14 in.) thick hinged at the top and bottom with Freyssinet hinges. The abutments are also on piles, and have the profile of a quay-wall of the Christiani & Nielsen type.

The prestressed hangars at Melsbroeck (*Fig.* 15) have two bays of 50 m. (165 ft.) by 45 m. (150 ft.) and one bay of 115 m. by 45 m. (350 ft. by 150 ft.). The prestressed beams have a span of 50 m. (165 ft.) and a depth of 2·9 m. (9 ft. 6 in.). In the bay of 115 m. the beams of 50 m. span rest on main prestressed beams of 45 m. span. The beams are hollow. The edge-beams are of rectangular cross section, and the other beams are wedge-shape. The longitudinal profile of the edge-beams is straight and the others are haunched. Each main beam weighs nearly 300 tons. The wedge-shaped beams have a maximum depth of 2·9 m. (9 ft. 6 in.) and a minimum depth of 2·5 m. (8 ft. 3 in.). The dead weight of 300 tons, plus the weight of secondary beams and a live load of 100 kg. per sq. m. (20 lb. per sq. ft.) produce a total weight of 500 tons. The allowable tension in the concrete is 150 kg. per sq. cm. (2150 lb. per sq. in.) and in the steel 90 kg. per sq. mm. (128,000 lb. per sq. in.). The concrete has a crushing strength of 450 kg. per sq. cm. (6400 lb. per sq. in.) and the wires have a tensile strength of 150 kg. per sq. mm. (214,000 lb. per sq. in.). The total prestressing force was 1471 tons, produced by 424 high-tensile wires of 7 mm. diameter tensioned at 90 kg. per sq. mm. (128,000 lb. per sq. in.). The loss of prestress was estimated to be 12 per cent. The maximum diagonal tension near the supports of the beams was 18 kg. per sq. cm. The beams were precast on the ground.

PORTUGAL

By PROFESSOR A. TEIXEIRA-REGO

UNIVERSITY OF OPORTO.

IN Portugal and Portuguese overseas possessions reinforced concrete has been used for structures of great size and of outstanding design, especially in the past twenty years. Many of these structures are excellent examples of good architecture, and many long-span floors carrying heavy loads have been built. The increasing use of concrete is due to the work of a number of specialists trained at the two most important technical colleges in Portugal, namely the Faculdade de Engenharia de Porto and the Instituto Superior Técnico de Lisboa. As a result

Fig. 1.—Palácio do Comércio, Oporto.

of the Government's efforts to preserve the national characteristics of architecture and building, there are no foreign building technicians in Portugal.

At the beginning of the century, French specialists introduced reinforced concrete into Portugal and created a demand for the new material, and they were quickly followed by Portuguese engineers who had studied the new material. In this period large buildings, such as the S. João theatre and the Grandes Armazens Nascimento, were built in Oporto, and are to-day worthy of admiration. In Oporto, where there were many old houses in narrow streets, the danger of fire was enormous, and the advent of reinforced concrete largely contributed to reducing the number of fires. This was a real triumph for concrete, and to-day nearly all new buildings are constructed of this material.

Some of the buildings recently built in Oporto are remarkable both for their size and appearance. The Palácio do Comércio (*Fig.* 1) provides accommodation

Fig. 2.—Palácio Atlântico, Oporto.

for hundreds of tenants in the business centre of the city. The Palácio Atlântico (*Fig.* 2) is also built entirely of reinforced concrete, and many large garages have been built recently, including multiple-story structures. A noteworthy structure is the Palácio dos Desportos (*Fig.* 3), which is to be completed this year; the dome has a diameter of about 300 ft.

Other notable reinforced concrete structures in Oporto include a fish market, a new town hall, the Pedras Rubras airport with a shell roof, and the markets of Bom Sucesso (*Fig.* 4) with Stahlton prestressed floor units, and Matosinhos

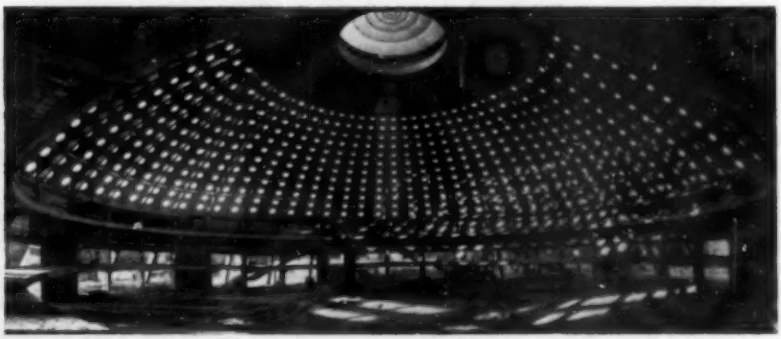


Fig. 3.—Palácio dos Desportos, Oporto: To be completed 1956.

Fig. 4.—Market at Oporto.

market (*Fig.* 5). Amongst factory buildings mention may be made of the Fábrica do Mindelo, a textile mill with beams of 110 ft. span.

In Lisbon an enormous amount of new building is in progress, mostly in concrete. Tall buildings and wide covered areas appear in succession, forming an harmonious ensemble of brilliant colours and graceful façades, and will form a beautiful city emerging from the old and monotonous Lisbon of the nineteenth century. Splendid buildings line the new streets, avenues, and squares of the new quarters of the Portuguese capital. The new theatres of Lisbon rank among the most notable in Europe; the Monumental, S. Jorge, Império, Alvalade, and other theatres are magnificent examples of the application of reinforced concrete. There are also a new hospital, stadia such as the Estádio Nacional, the Estádio de Carnide (*Fig.* 6) in reinforced and prestressed concrete, the Estádio do Sporting (still under construction), new buildings for the University City (also under construction), cold storages, two new stations, hangars at Sacavém airport, new schools, the reconstruction of official buildings, and, finally, the great work now in course of realisation—the Lisbon underground railway. Throughout the country during recent years very many schools, post offices, hospitals, courts of law, and other public buildings have been erected. As is the case throughout Europe, a large part of the national budget is spent on military installations as part of the Western Europe defence plans.

Fig. 5.—Matosinhos Market.

Fig. 6.—Stadium at Lisbon.

Fig. 7.—Bridge at Coimbra.

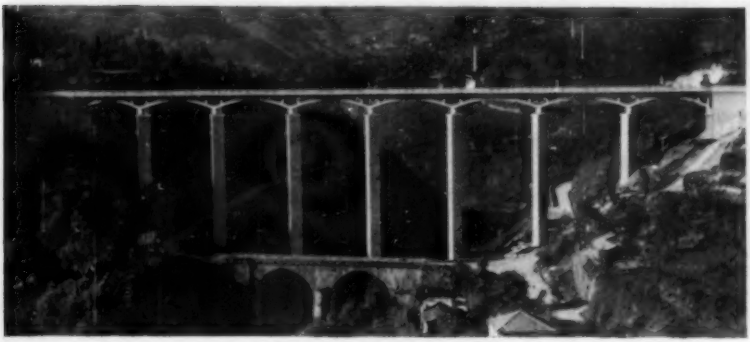


Fig. 8.—Bridge over the River Cávado.

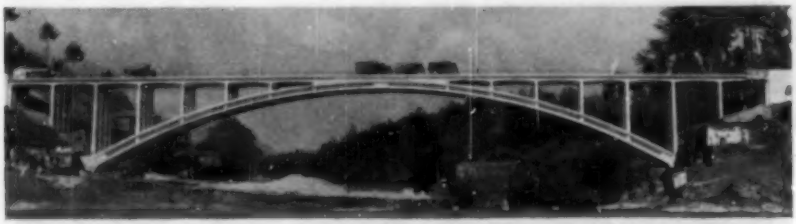


Fig. 9.—Bridge over the River Sousa: Span 375 ft.

Mention must be made of the reconstruction of much of the old academic city of Coimbra, where the whole of the surroundings of the famous university, consisting of narrow and unhealthy streets, are being demolished to make way for wide streets with reinforced concrete monumental buildings accommodating the chief faculties, laboratories, and other parts of the University, which is one of the oldest on the Continent.

In the construction of bridges, harbour works, silos, hydro-electric works, and irrigation schemes, reinforced concrete has made an important contribution. Among bridges may be mentioned the new bridge at Coimbra (*Fig.* 7), the bridge over the river Cávado seen in *Fig.* 8 (the old bridge, flooded by the waters of the Canicada dam, is seen in the foreground), the bridge (*Fig.* 9) with a span of 375 ft. over the river Sousa, the Duarte viaduct (*Fig.* 10) at Lisbon with a main arch spanning 300 ft., and the bridge over the river Tua (*Fig.* 11). The Arrábida bridge in Oporto, over the river Douro, will have a span of 886 ft., and will be one of the most beautiful reinforced concrete constructions in the world; work is about to be started on this bridge. Many reinforced concrete silos, built with sliding shutters, have been built throughout the country; they are generally circular, and some are remarkable for their great size. The policy of intense electrification has resulted in the construction of large hydro-electric schemes, with large concrete dams; these structures are among the most notable in Europe. In the harbours of the country, specially at Oporto and Leixões, reinforced concrete has been largely used in the construction of piers, docks, bridges, and other structures.

Prestressed concrete was first employed in Portugal by the writer in the

Fig. 10.—The Duarte Pacheco Viaduct, Lisbon: Main Span 300 ft.

Fig. 11.—Bridge over the River Tua.

year 1948, when the production of prestressed beams with bonded steel wire was started on a large scale at the Precomate works in Oporto. Since then prestressed concrete has been employed on an ever-increasing scale, and for floors (*Fig.* 12) of industrial buildings its use is now general. The first use of cast-in-place prestressed concrete was at a warehouse in Matosinhos in 1951; the roof (*Fig.* 13) has a span of 110 ft. and is built on the Freyssinet system; this was a very daring enterprise at that time. Later examples are the buildings of Fábrica de Celulose, at Cacia, with beams of 80 ft. span, the telephone exchange of the Anglo-Portuguese Telephone Co. in Oporto, a large garage in Oporto, and many other structures in Oporto, Lisbon, and Coimbra. Some prestressed bridges have been built, including the Vala Nova bridge (*Fig.* 14) with three

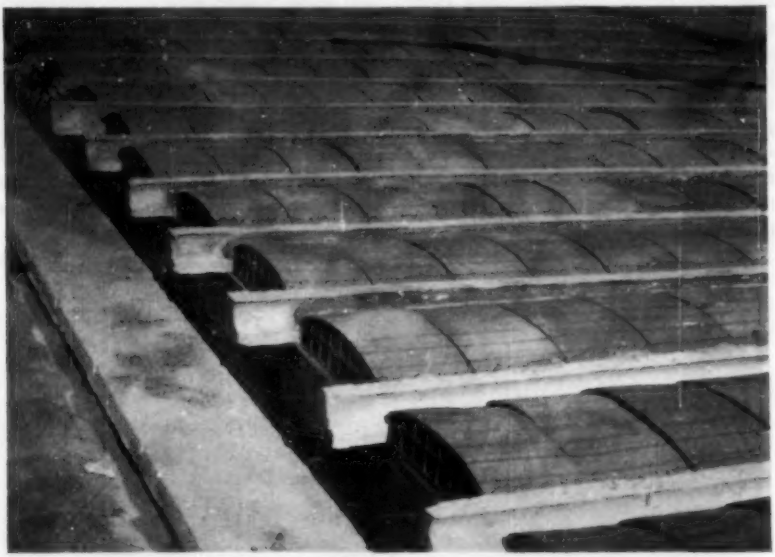


Fig. 12.—Hollow Clay Tiles between Prestressed Concrete Beams.

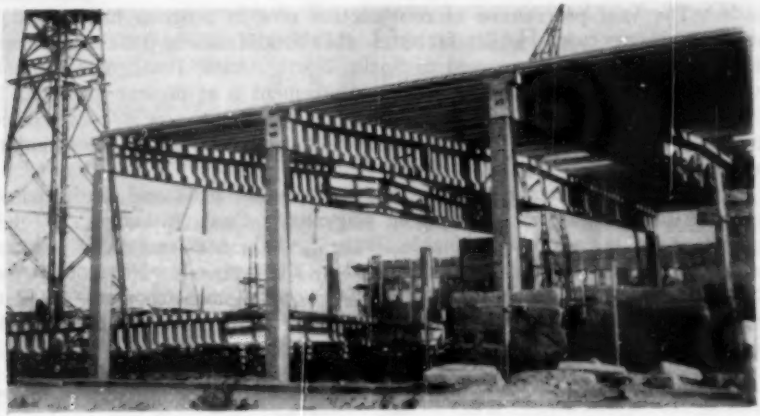


Fig. 13.—Store at Matosinhos: Prestressed Beams 110 ft. Long.

simply-supported spans of 120 ft., and various railway and road bridges. Several other prestressed structures are in course of erection, including the Almadafe bridge with a span of 155 ft., the reconstruction of Caminha bridge with twenty-two spans of 45 ft. each, and bridges at Aveiro with three 90-ft. spans. Also some three dozen bridges of about 100 ft. span are projected on the new motor-road leading to Leixões harbour. In all these works the Freyssinet system was employed, but the Magnel system has been used for two circular water tanks at Oporto, and the Gifford-Udall system in partially-prestressed sheds built with precast units.

Portugal produces good quality cement, which, although not having the high strength of some foreign cements, yet enables good quality concrete to be

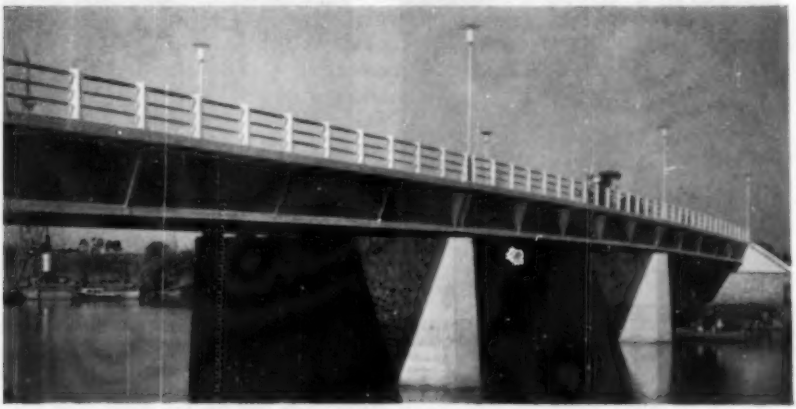


Fig. 14.—Vala Nova Bridge: Three Prestressed Spans of 120 ft. each.

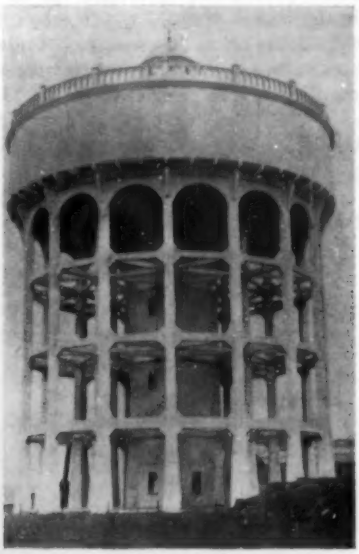
made. The vast programme of construction now in progress has caused the cement industry to extend its factories and, besides meeting the requirements of Portugal, cement is exported to Spain, North Africa, Portuguese territories oversea, and elsewhere. All the steel reinforcement is at present imported, but it is hoped that within a few years, when the steel works now in course of construction is in production, Portugal will be able to produce all the steel reinforcement she requires.

For some years research has been undertaken on plain and reinforced concrete at the Laboratório Nacional de Engenharia Civil, in Lisbon, by highly competent technicians, with valuable results, and the construction of important dams and bridges has been largely assisted by this research. None of the more important concrete works in Portugal has been carried out without the assistance of the Laboratory, and this has resulted in an increasing confidence in the properties of plain, reinforced, and prestressed concrete.

Two Early Water Towers in England.

Water Tower at Bournemouth. Built in 1905.

[Total height 45 ft. Capacity 15,000 gallons.]



Water Tower, Newton-le-Willows, Lancs. Built in 1905.

[Height to top of tank 83 ft. Capacity 300,000 gallons. The bottom of the tank is 5 in. thick, and the wall tapers from 6 in. at the bottom to 5 in. at the top.]

U.S.A.

Reminiscences on Cement Research.

By R. H. BOGUE.

Formerly Director of the Portland Cement Association Fellowship, U.S. National Bureau of Standards.

Foreword.

I am happy to offer my congratulations to " Concrete and Constructional Engineering " on the completion of fifty years of noteworthy publication, and I am honoured at being invited to submit a few reminiscences of events that have occurred during my association with the cement industry.

Statistics are always interesting, so let us first look at a few figures. In the United States, the production of Portland cement in 1900 was 1,424,000 long tons. By 1925 it had risen 19-fold, to 27,136,000 tons. By 1954 the increase had risen 32-fold to 45,536,000 tons. The number of plants producing Portland cement was 50 in 1900, 138 in 1925, and 157 in 1954. Inasmuch as the 32-fold increase in production was accompanied by only a 3·2-fold increase in the number of plants, it is obvious that each plant is producing an average of ten times as much cement. The new highs in production were due, therefore, to expansions and improvements in plants. But expansions and improvements in facilities for manufacturing cement are the result and not the cause of the sky-rocketing demand. It would be of no avail to produce a mountain of cement if it could not be sold and made into commercially acceptable and economically profitable items. Portland cement is the principal constituent of the most widely-used material of construction of our day. About one-third more concrete is used as a basis of construction than all other construction materials combined : iron and steel, lumber, structural clay, non-ferrous metals, brick, glass, stone. . . . But a material that was satisfactory a decade ago is rarely satisfactory to-day. No industry can stand still. If it attempt to do so its competitors will rise around it and it will find itself, willy nilly, going backward.

The experience of industry is that the sine qua non of progress is research. In a recent number of " Industrial and Engineering News " (July 18, 1955, page 2980), Raymond H. Ewell, Assistant Director of the National Science Foundation, discusses the role of research in economic growth, and concludes that " Research may be the most important single factor in increasing productivity." The current national expenditure for research and development in the U.S.A. is about $4 billion a year : as much as was spent for that service in the entire period from 1776 to 1933. And research investment, says Ewell, brings the highest rate of return of any investment, 100 to 200 per cent. per year, although it may take 25 years to develop the full value.

The cement industry is no exception in the benefits realized from research. Before the turn of the century the ultimate purpose of a cement laboratory was to experiment on the clinkering characteristics of great numbers of combinations of raw materials and to relate the resulting cements to the properties of the concretes made therewith. During the first quarter of the present century volumes of statistical data were accumulated for the establishment of tests for specifications and the design of concrete mixtures. Research came to its own in the second quarter, when chemists and physicists in the cement laboratories

throughout the world applied the laws of science to the art of cement production and utilization. The success of their efforts is attested by the enormous expansion of the industry along lines that were stimulated and directed by such information.

During the last few years advances have been quickening which seem to mark the introduction of a new era in the scientific thinking of the industry. New tools are challenging the investigator in the exploration of the ultimate molecular and crystallographic structure of the phases of which cement and its hydration products are composed. The importance of these structures is explained by the character of information that can be gained from their solution. The manufacturer is thus given a new means of control of the production and quality of his product, designed to meet the advancing needs of the construction industry, and the building engineer a new means for control in the formulation and utility of his concrete, designed to meet any combination of commercial requirements.

My premise, therefore, is that the vast increase in the demand for and the production of Portland cement during the past half century is, to an important degree, the direct result of intelligent constructive research and development. My own activity in this field began in 1924 when, stimulated by the endorsement of the Hoover Committee for the encouragement of basic research on building materials, the Portland Cement Association Fellowship was inaugurated at the National Bureau of Standards. The findings of the Fellowship have been described in some seventy technical papers. The purpose of the present contribution is not, however, to report results of research, but rather to recall a few of the more personal sidelights that have illuminated our path over the years.

Basic Research.

I have always believed that a director of research should actively pursue the art of clairvoyance. He should make it his business to foresee the problems that may be faced by his industry at some time in the future, direct research to their solution, and have the answers before the industry knows that the problems exist. Basic research differs from statistical or empirical research in that it aims at the attaining of fundamental information which is universally applicable. Time was when a director of research had to justify each research project in terms of an immediate objective. That time, I think, is mostly gone. Now he can rightly say, as I have done, " I have no idea just wherein this basic study will create more dollars, but that it will prove invaluable in a thousand ways I have no doubt whatsoever."

The results of basic research have so often borne out the correctness of this point of view that apologies are no longer needed. After my first report to the Portland Cement Association, Robert Lesley, Founder of the Association, rose to say, " Gentlemen, I do not know exactly what this young man is venturing to do with the cement industry, but I am convinced that in his research he sees markets and uses that have escaped us. So I shall vote for his programme." Thus basic research from the beginning was at the root of all our thinking. The applications were the branches of our tree. Our programme began with studies on phase equilibria in the cement systems and on thermodynamics of the hydration process. A multitude of auxiliary studies had to be followed for providing new tools and test procedures and for making the results applicable to the problems

of the cement manufacturer or the constructional engineer. With the passing of time new avenues of approach were opened up and new tools developed which made it profitable to re-explore old systems.

Everything changes, and the laboratory is no exception. What used to be a chemical laboratory is now a maze of electronic, spectrographic, or X-ray machines, but each item improves the depth of penetration into a material or the speed of getting answers. In the early years I have sat for eighteen hours at a stretch on a differential thermal analysis project, and still never got two identical curves of the same sample. Now an operator can set the dials, go home for the night, and in the morning find a battery of samples completely and precisely defined. The analysis of a sample for sodium or potassium oxides used to require the greater part of a week, but now a couple score of samples can be more precisely analysed with a flame photometer in a day. In recent years the techniques of X-ray single-crystal diffraction and electron optics have opened the door to a further probing of the ultimate structure of our materials. The high-temperature centrifuge developed by Newkirk and the hot-wire apparatus developed by Ordway provide means by which the time required for a phase or crystal study may be shortened a hundred-fold. And the equations of Dahl permit the utilization of these new techniques in the exploration of poly-component systems. The deeper we venture the more we learn, but the more we still have to learn. That is the way with science.

Burnability of Raw Mixtures.

One of our early studies was on the burnability of raw mixtures of various mineral compositions and finenesses. But first it was necessary to find a measure of burnability. Since all raw mixtures contained limestone or other calcium carbonate which converted to calcium oxide on heating, and the oxide entered into combination with silica and alumina and ferric oxide during the course of clinker formation, it appeared that the completeness of the reactions could be gauged by the degree to which the free lime disappeared from the mixture. Hence the method for free CaO which had been discovered by Emley was adapted for our special conditions. With later modifications by numerous investigators, this method has become commonly employed in the industry.

Another procedure involved the examination of the clinker for the new compounds produced. At first, observations were made on the powdered clinker for index of refraction and other optical properties of the separate grains. Staining methods were tried without marked success, but when sections were prepared and examined by reflected light the complete pattern of the grain could be dimly seen. The problem was to make this pattern stand out clearly, so that the constituents of the grains could be sharply differentiated and positively identified. The solution came through etching techniques developed by Insley, Tavasci, Parker, Ashton, Brownmiller, and others. And when the process was further perfected by the use of polished and etched sections, cut to a thinness of 5 to 10 microns as by the processes of Brown and Ward, observation of given crystals could be made by both reflected and transmitted light. The phase composition could then be measured with considerable precision. From these studies on burnability, we discovered the role of the fluxing constituents, alumina and ferric oxide, and the range of compositions wherein each was effective. The reason

why alumina improved burnability within one range, and ferric oxide within a different range, became known only after the studies on phase equilibria had provided the boundary-curve and invariant-point data.

The statistical effect of magnesia on durability was learned, but explanation awaited the solution of magnesia-phase systems by Hansen. The effects of the alkali oxides were observed, but here again the explanation was provided only many years later with the solution of alkali systems by Brownmiller, Taylor, Eubank, and Newkirk. Thus at every stage of our programme, statistical data could be easily obtained, but the chemical laws governing that action were known only at the conclusion of long-period basic research.

In the cement plants, the raw materials were ground by open-circuit methods which resulted in a kiln-feed containing a considerable amount of impalpable powder and also a substantial amount of rather coarse grains. Our study indicated that some materials, as limestone, did not need to be ground finer than No. 100 or 200 sieve, but that other materials, as quartz, required a fineness of minus No. 325 sieve to combine satisfactorily. In open-circuit grinding, much of the limestone was ground finer than was necessary, whereas portions of the quartz often were not ground finely enough. The remedy was a closed-circuit system, which has now become almost universal.

Pilot Plant.

It was to study the effects of changes in composition and heat treatment of clinkers on the properties of concretes that we built experimental kilns. The first was a square gas-heated fire-brick box. The charge consisted of raw materials moulded into bars about 10 in. long and 1 in. square in cross section. A more flexible furnace was an 8-ft. gas-fired rotary kiln lined with magnesite brick and having an effective diameter of 5 in. This was fed with pellets of raw mixture about $\frac{1}{2}$ in. diameter. With this kiln we made some 700 batches of about 75 lb. each, or more than 52,000 lb. of clinker. Ground to various finenesses with various additions of gypsum, the cements were examined by a great diversity of tests designed to define the quality of the products.

No single piece of equipment has been more useful in the final justification of a projected change in operation. The precise techniques of phase equilibria furnished the basic data, but the pilot plant indicated their applicability to commercial production. The popularity of this type of equipment is attested by requests from a considerable number of laboratories for descriptive blueprints. I have seen many such plants in operation in many countries.

Special Cements.

LOW-HEAT CEMENT.—During the planning of Hoover dam the engineers proposed to place a greater mass and deeper sections of concrete than ever before had been attempted. The thermal conductivity was known to them, and on calculating the rate of heat loss from the structure it was learned that unusually high temperatures would be developed in the setting concrete. The high temperatures as such were of little moment, but the contraction on cooling could be of such magnitude as to impair the appearance of the structure, jeopardize the proper functioning of the hydroelectric machinery, or even threaten the security of the dam. The question was asked: How can the cement be made so as to

evolve much less heat than would follow from the use of the general purpose (Type I) cement? We were fortunate to have the answer, for we had recently completed a basic study on the heats of hydration of the cement compounds, and had completed an exploration of the iron-containing systems. The greatest amount of heat was found to be evolved from the hydration of the tricalcium aluminate, and next to that was the tricalcium silicate. If we could omit the former in clinker near to zero and reduce the latter, we would have a low-heat cement.

We had learned that the iron compound in clinker was a solid solution lying on a line between dicalcium ferrite and the hypothetical dicalcium aluminate, having a composition close to $4CaO.Al_2O_3.Fe_2O_3$. Furthermore, tricalcium aluminate would be converted to tetracalcium aluminoferrite by the mere addition of iron oxide to the raw mixture. And tetracalcium aluminoferrite was a low-heat compound. Hence a cement mixture potentially high in tricalcium aluminate could be .nade into a low tricalcium aluminate mixture by adding iron ore or other iron-rich materials to the raw mixture. The tricalcium silicate could be replaced by dicalcium silicate by reducing the lime in the mixture. The product would be a low-heat cement. The sequel followed quickly. John Trainer, President of the Riverside Cement Company, sent his research chemist, Hubert Woods, to Washington to confer with us and check our findings. On Woods' return, Trainer accepted a Government order for 8400 tons of low-heat cement before a pound had been produced commercially. The cement was first tried out in a much smaller project, the Pine Canyon dam. Since then it has been used in several large structures and has been accepted in the Federal and A.S.T.M. specifications as Type IV cement.

When the Tennessee Valley Authority was considering cement for use in some of the dams under its jurisdiction, it was decided that a cement should be specified that would approach the low-heat type, but go less far in its reduction of tricalcium aluminate and tricalcium silicate. This cement was called Type B, but later became incorporated in the specifications as Type II cement.

SULPHATE-RESISTING CEMENT.—My introduction to the destructive effects of sulphates on concrete came during a trip with Duff Abrams in 1926. At Montrose in Western Colorado the Portland Cement Association had established an experimental plot where a large number of variously-made concrete cylinders were partially submerged in a field seeping with sulphate waters. At the end of a few years only the cylinders that were well protected by surface coating remained. The others were mostly heaps of salt-encrusted pebbles.

On returning to Washington I followed the lead of Thorvaldson and Miller by initiating an extensive series of tests for sulphate action. Mortars were made of the pure cement compounds, of laboratory cements of controlled composition, and of commercial cements, and submerged in various corrosive solutions. From these studies came the conclusive information relating sulphate resistivity to clinker composition, and Type V cement became incorporated into the Federal and A.S.T.M. specifications.

HIGH-EARLY STRENGTH CEMENT.—A recognition of the early-strength-imparting characteristics of a high-lime cement probably goes back to Le Chatelier in 1882 and the Newberrys in 1905. But, so far as I am aware, the first commercial high-early-strength Portland cement was produced in the U.S.A. in 1926

by Durbin of the Lone Star Cement Corporation under the trade name of " Incor ". The principal feature of manufacture seems to have been a very thorough combination of the constituents high in lime, which was brought about by double burning of the clinker. In an extensive study at the Bureau of Standards and Fellowship laboratories, it appeared that high early strength was imparted to a cement chiefly by the tricalcium silicate. The dicalcium silicate was found to give equal strengths at ages of six to twelve months, but only the tricalcium silicate hydrated rapidly enough to impart high strength in a few days. High early strength resulted, therefore, from a high tricalcium silicate-dicalcium silicate ratio. Finer grinding also accelerated the rate of hydration. The general adoption of such cements by the industry followed quickly, and the particulars for them were incorporated as Type III into the usual specifications.

Even the Type I general purpose cement benefited by the trend towards higher early strength. Whereas the usual curing period for concrete roads had been twenty-one days, improvements in the Type I cements along the foregoing lines brought about a lowering of the curing period to seven days. By the use of the Type III cements, the time was further reduced to three days. The pressure towards higher early strength was so great that at one time there was considered seriously the possible desirability of the industry going full-cry to Type III cement, with the virtual elimination of the Type I product. My personal opinion was that such action would not be in the best interest of the industry. After concrete is in place, nearly every action, either mechanical or chemical, that is brought to bear on the structure will be a degrading action, tending to a weakening of the structure. Such action can be counteracted only by the continued hydration of certain cement compounds. Tricalcium silicate hydrates rapidly, so only a coarsely-ground increment of it would be capable of providing a continuing hydration over a long period. But continued hydration is provided to a marked degree by the slowly-hydrating dicalcium silicate. Hence I would favour for general purposes a clinker that contains a significant amount of dicalcium silicate, and one not ground to excessive fineness. Fortunately, the proposal for the change did not gain general acceptance.

The Alite Problem.

Who is there among the senior investigators that does not recall the long and sometimes heated polemics on the " alite " problem ? Probably first discovered under the microscope of Le Chatelier, and again independently by Tornebohm who gave it the alphabetical name, I suppose nearly every cement researcher in the world has had his fling at defining its constitution. Shepherd and Rankin agreed with Le Chatelier that this principal compound of clinker was tricalcium silicate, but Janecke emphasized the necessity of alumina for its formation and proposed a ternary formula of the composition $8CaO.Al_2O_3.2SiO_2$. Janecke's premise was refuted by Bates, who prepared alite without the presence of alumina, but Dyckerhoff jumped both proposals (although admitting the existence of both) by affirming that the temperatures in the kiln were such as to allow only the formation of a solid solution of CaO in beta dicalcium silicate. Kühl could agree with none of the earlier contributors, and considered alite as a solid solution of silicates and aluminates.

In 1926 I learned that Walter Dyckerhoff was planning a visit to South

America and thought he might be persuaded to come to Washington. In our laboratory, Hansen had confirmed the findings of Shepherd and Rankin but I believed that a few weeks of joint study with Dyckerhoff, assisted by the experience of Rankin and Wright at the Geophysical Laboratory, would be more instructive to all of us than volumes of disputatious papers. The plan was accepted with the happy ending of a joint paper in which tricalcium silicate triumphed as the constitution of alite. Further confirmations were established by Brownmiller.

Guttmann and Gille had at first favoured a solid-solution theory but, on examining fractions of alite that had been separated from clinker by centrifugation, found only tricalcium silicate. And finally Janecke announced that a volatilization of silica in his preparations had resulted in a miscalculation, and he now acknowledged the existence of tricalcium silicate in alite. Most of us now felt we could relax and consider the problem settled, but that is not the usual experience of scientific progress. Came crystal structure analysis by X-ray single-crystal techniques. From the data obtained with these methods, Jeffery concluded that the composition of alite was much more complex than had been supposed. He calculated its composition to be represented by the formula $54CaO.16SiO_2.Al_2O_3.MgO$. In other words, from 18 molecules of tricalcium silicate, one SiO_2 had been replaced by Al_2O_3 and another by MgO.

The meaning seems to be this. Nature is essentially simple in her structures, but that simplicity holds only in the grosser structures and not with the very small dimensions or forces. This is especially the case along the crystal peripheries that mark the interfaces with other systems. Here there often is an active exchange of atoms or ions, seeking new marriages in new worlds. To the low-power probing with the classical tools of a decade ago, the active fringe was not seen, although many evidences suggested a zone of uncertainty. With the X-ray diffraction apparatus and the electron microscope the fringe appears, but the play of forces negates a precise stoichiometric defining of the dynamic equilibria except under the most rigidly-established conditions. Generalization seems to be possible up to a point but no farther for, in the manufacture of cement, conditions are never known with sufficient precision to assume exact prediction of results.

Abbreviated Symbols.

I have often been asked how and where originated the abbreviated symbols commonly employed by cement chemists. Believing that they were first employed on page 43 of the paper by Rankin and Wright on "The Ternary System $CaO–Al_2O_3–SiO_2$", published in the "American Journal of Science", **4**, 39 (1915), I asked George Morey if he had any personal recollection of how those symbols came to be used. Morey told me that he remembered the exact occasion very clearly. The paper was being put into shape by an editorial committee when John Johnston, who was then a member of the staff (later Chairman of the Department of Chemistry at Yale University and Director of Research of the U.S. Steel Corporation), became very much exasperated with the cumbersome mineralogical formulæ. It was his suggestion that those formulæ be abbreviated to the forms given. It is interesting to note that in this paper the abbreviations do not begin

until more than halfway through the article. In the remaining portions, however, the abbreviations occur very commonly.

P. H. Bates followed the lead of Rankin and Wright in his paper on " Cementing Qualities of Calcium Aluminates ", published as Technological Paper 197 of the Bureau of Standards in 1921. His abbreviations differ, however, from those of Rankin and Wright in that he uses such forms as 3CA, 3C5A, 2CS, 3CS, etc., in place of C_3A, C_5A_3, C_2S, C_3S, etc. Bates continued to prefer his form of symbol, I believe, to the time of his retirement, and a few other writers have followed suit. The advantages of Johnston's form, however, appeal to most writers, and his abbreviations have commonly been employed by investigators in the cement industry. It was a natural extension of this idea that caused us to apply the system to ferric oxide in our Paper 21 in 1929, to sodium oxide in our Paper 25 in 1932, to potassium oxide in our Paper 30 in 1935, and to magnesia, lithia, titania, and water in the first edition of my book in 1947.

Glass in Clinker.

Early in our work we learned that crystalline tricalcium aluminate gave rise to high heats of hydration and was also the chief offender in the disintegration of concrete in sulphate solutions. Projects in our pilot plant made it possible to obtain clinkers in which the alumina and iron, nominally present as liquid in the burning zone of a kiln, could be frozen to a glass. Thus crystallization of tricalcium aluminate was avoided. The alumina-rich glass was found to be much less prone than the crystalline tricalcium aluminate to produce high heats of hydration or sulphate reactivity. In commercial operation, the high-glass clinker could be obtained by a rapid cooling of the clinker.

Another effect of glass was found in connection with the phenomenon of delayed expansion of concrete. Many structures had been found to remain sound for a few years, and then to expand to such an extent as to disrupt the structure. A systematic study by Lerch revealed that this was due to the presence of crystalline magnesia (periclase), which dissolves in the liquid of cement systems to the extent of about 6 per cent. It was found that periclase, so dissolved and solidified as glass, did not give rise to later expansions. So here again the remedy was to cool the clinker rapidly in order that a maximum of the liquid, with its dissolved magnesia, would be frozen to glass.

An accelerated test for the presence of periclase in excessive amounts was developed in the autoclave test for soundness, and a maximum expansion of 0·5 per cent. for standard 10-in. neat cement bars was incorporated into the specifications. This test, first proposed by the cement manufacturers before the specification was adopted, is an excellent example of a self-imposed restriction for the purpose of ensuring a high quality product.

Air Entrainment.

One of the most serious deficiencies of Portland cement concrete often experienced in northern climates had been its tendency to scale and disintegrate under repeated cycles of freezing and thawing. This action on highways was accelerated by the addition of salts for the purpose of melting the ice. Many efforts were made to explain and overcome this action, which was common to many, though not all, Portland cements. I am told by Myron Swayze, Director

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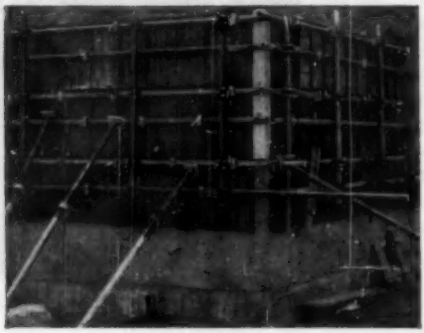

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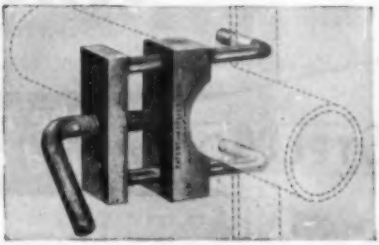

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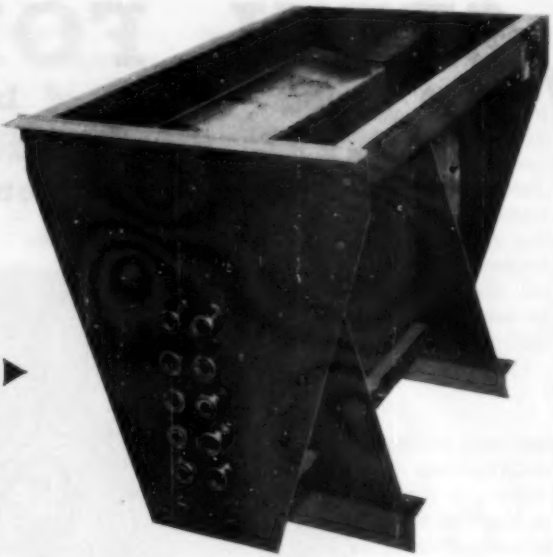

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of Research of the Lone Star Cement Corporation, that by 1936 he and L. R. Pritchard, then Chief Chemist at Hudson, had found some important relations: (1) That the exceptional durability of the cement produced at their Hudson plant was due to oil leaking into the cement from Griffin mills, and (2) that additions of resin during grinding also improved durability. Their attempts in 1937 to introduce a resin-containing cement to the market was, however, unsuccessful. Confirmation and explanation were demanded.

In 1936 the New York State Highway Commission was considering the addition of natural cement to Portland cement for the construction of principal highways. As a check on this proposal, Frank Jackson, Engineer of Tests of the Bureau of Public Roads, initiated a comprehensive series of tests, using a variety of Portland cements and Portland-natural blends. The results were so striking that he invited a number of cement chemists and engineers to Arlington to observe and confer on the cause. The cylinders made with Portland cement concrete had, almost without exception, shown signs of serious disintegration within a relatively few cycles of freezing and thawing. Those made with the Portland-natural blends were mostly in good condition after many cycles. I attended this meeting, and long afterward retained the impression that I had been present at the birth of air-entrainment. In these tests the Hudson Lone Star Portland cement had performed beautifully. The only reason that could be advanced by Swayze was the addition of the oil that leaked from the old Griffin mill. With that clue, tests and research were immediately begun in a score of laboratories. In a short time it was learned that the natural-cement concretes contained air, and that the leaking oil also had incorporated air into the Hudson Portland cement. And it was found that entrained air of the proper size and amount was critically effective in preventing disintegration under repeated cycles of freezing and thawing. A few additives for producing air entrainment, either at the plant or at the mixer, have been promoted, tested, and approved. Thus the discovery of the cause of low durability was accidental, and its cure founded upon the provident leakage of oil by defective mills! There is no reason to believe that important improvements cannot be further developed through a systematic survey.

Postscript.

I could go on for some time recalling incidents that have left their mark on the forward progress of the cement industry. But I shall bring this rambling monologue to a close with just a word about my foreign friends. For nothing in my experience in the industry has given me more of joy and gratitude than the warm friendships I have been so fortunate as to have made among my colleagues in the cement plants and laboratories of the world.

It began more than a quarter of a century ago when F. M. Lea, now Director of the Building Research Station of England, came over to study with us for a year, a year in which he initiated his exploration of the four-component system CaO–Al_2O_3–Fe_2O_3–SiO_2, later completed in his own laboratory with T. W. Parker. And when Walter Dyckerhoff, later director of the Dyckerhoff Cement Company of Germany, came to study with us on the nature of alite. Visitors journeyed to Washington in large numbers until we had talked with most of the leading authorities on cement in the world.

In 1936 the World Power Congress met in Washington, which brought here Lennart Forsen and Stig Giertz-Hedstrom of Sweden, and again F. M. Lea. Almost daily we sat together at the sessions, and in the evenings talked about our favourite subject: cement research. It was then that we planned the Symposium on cement which took place two years later in Stockholm. Following the Symposium, on his islands in Finland, Forsen entertained Lea, Thorvaldson, Giertz-Hedstrom, Swayze, and myself. Each of us bought a little fir tree and we rowed out to a little island that had no trees nor any name, and each planted his tree. We dedicated the spot "Committee Island".

Such was the beginning of my reception by my European friends. In 1950–51 I was invited to lecture in Madrid and Barcelona. In 1952 we held another great Symposium on Cements in London. In 1954 I was invited to participate in the 27th International Congress of Industrial Chemistry in Brussels. At each place visited I have been received with the same open arms, the same cordiality. From England and Sweden and Belgium and Denmark to Spain and Germany and Switzerland and Italy, our mutual interests and human fellowship have cemented friendships that are not defined by national or geographic frontiers.

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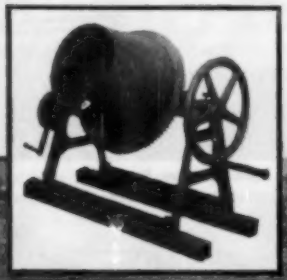

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GREAT BRITAIN

SOME RANDOM NOTES

By an Engineer in Practice for Fifty Years.

At the beginning of this century reinforced concrete work was commencing in this country under the direction of French engineers who had already gained considerable experience in the organisations of Hennebique, Considère, and Coignet. These and other pioneers developed systems of design, and licensed contractors for their execution, and before 1910 many notable reinforced concrete works were built in these islands.

Special Bars and Patent Rights.

These methods of construction were soon followed by the advocates of special proprietary bars such as the indented bar and the Khan bar, both of American origin. Expanded metal reinforcement was also used. The purpose of such businesses was to sell reinforcement and, in order to do so, they made designs so that contractors could quote for the design work as well as the construction, frequently on a lump sum basis. With the advent of these and other firms undertaking design, competition grew quickly, with the result that these new methods of construction were often exploited under a system of competitive tendering on competitive designs.

During the first ten years of this century detailed knowledge of the design of reinforced concrete was developing but was difficult to acquire. There were then few books on the subject, and such as existed were mostly in Continental languages. The various patents underlying proprietary systems of design were not easy to comprehend, and the merits of the various proprietary reinforcements were frequently obscure. Indented bars were advocated on account of their advantages in mechanical bond between the steel and concrete. They were then square bars of fairly hard steel having a tensile strength considerably above that of mild steel and were joggled in two directions perpendicular to their sides. Other bars providing mechanical bond have since been introduced to permit working stresses higher than those permissible in plain mild steel bars, such as twisted steel bars, ribbed bars, twin-twisted round bars, and several others. The Khan bar in the early days consisted of a square bar rolled with continuous projecting flats across one diagonal. These flats were sheared longitudinally at intervals over some distance and turned up at inclinations of 45 deg. to the diagonal axis of the bar. Thus in a beam the sheared flats or wings formed inclined stirrups.

That patent rights underlying proprietary systems of design lacked clarity may be seen by referring to the litigation that took place from 1906 to 1909 between the Hennebique system (represented by Mouchel) and Coignet because Coignet's licensed contractors (Messrs. William Cowlin & Sons, Ltd.) had made and driven piles of reinforced concrete. This was claimed to infringe Hennebique's patent of 1897. The case went to the House of Lords where judgment was given for the defendants on the ground that Hennebique's patent had been anticipated in Great Britain by Brannion's patent of 1871 as well as by an American patent.

By about 1910 many contracting firms of standing were undertaking both design and execution of reinforced concrete, using plain round mild steel bars, binders, and stirrups, on the lines of present-day practice, without recourse to specialist systems or materials.

Design.

It was about fifty years ago that young college-trained embryo engineers began to enter the profession in sufficient numbers to acquire some small influence in civil engineering. They brought their slide-rules with them, and instances are known where both the slide-rules and the mathematically-trained would-be engineers were regarded as " curiosities " by the " practical man ". A college training was in those days sometimes considered to be a comfortable way of avoiding the examination of the Institution of Civil Engineers, which had then recently been introduced as a necessary accompaniment to the requisite experience for acquiring the designation " A.M.I.C.E."

It was perhaps fortunate that the introduction into constructional engineering of slide-rules, college-trained engineers,

and reinforced concrete was more or less simultaneous, since the practice and development of this new material required slide-rules to deal with the masses of arithmetic involved as well as the college-trained mind to handle it.

From the point of view of design the revolutionary change lay in the principle of continuity inherent in a monolithic structure, whereby in floors and beams the then familiar bending moments denoted by $\frac{wl}{8}$ were replaced by such approximations as $\frac{wl}{10}$, $\frac{wl}{12}$, etc., or more accurate assessment. It also took time for engineers to realise that bending moments on floors were actually in part resisted by the columns supporting them, a reality that still defies precise computation. Fifty years ago there were very few engineers able to design in reinforced concrete, whereas now there are very few structural engineers who are not able to design in this composite material.

The first official publication in this country on formulæ for design, working stresses, etc., the forerunner of present-day codes of practice, was the Royal Institute of British Architects' Report of 1906, which was followed by a Second Report in 1911. The first London County Council Regulations were published in 1915 and were much used as a criterion for design both at home and abroad. Design stresses in concrete were then 600 lb. per square inch compression in bending and 60 lb. per square inch in shear; a tensile stress of 16,000 lb. per sq. inch was permitted in the steel. A section of a rectangular beam at full working stresses had in consequence a moment of resistance denoted by $95bd^2$ compared with a moment of about $200bd^2$ to-day. However, as it is frequently not expedient in ordinary building construction to stress the concrete to its maximum, these differences are in fact not as great as might appear at first sight.

Apart from the material help given by the technical press and by books, information and the results of experience were disseminated by the Concrete Institute which was formed in 1908. To the regret of many of its founders the scope of this Institute was broadened in 1922 to include other structural materials, and its name was changed to the Institution of Structural Engineers. One of the results of this change was the creation in 1932 of the Reinforced Concrete Association by a number of engineers who considered that the industry should have its own representative body.

Improvements of Concrete.

Portland cement was by 1900 a fully reliable material, and its strength, though far below present-day strengths, was sufficient to produce good concrete. It had already been established that, to get good tensile strength in briquettes 1-in. square, either of neat cement or of cement and standard sand, a rigid control of the proportion of water was required. So little gauging water was used that the material was compacted in the moulds by means of a standard spatula.

Hand-mixing of concrete was common, with little control over the quantity of mixing water; turning the material over twice and the establishment of uniform colour were the principal points emphasised in specifications. The result was a tendency to use an excessive amount of water so that the concrete would flow easily between the bars. The time of mixing was also frequently very short, and some of the early concrete mixers were advertised under the slogan "a mix a minute", which presumably included the time for charging and discharging. Such methods did not tend to produce the best quality of concrete, the function of which, it should never be overlooked, is not simply to provide the necessary strength and cohesion in the structure, but particularly to provide the necessary protection both for the reinforcement and for itself by keeping out the wet and the effects of frost.

It was not until after the first world war that Professor Duff Abrams in America, as a result of extensive tests, published his water-cement-ratio curves for the strength of concrete with various water contents, and stated that concrete rich in cement was frequently stronger than concrete made with a lean mixture only because in a rich mixture less water per unit of cement would in all probability be used. These reports received great publicity, and it became generally known that ideally only sufficient water should be used to hydrate the cement and to

Some views of the open-air swimming pool at the Skegness Holiday Camp. By kind permission of Messrs. Butlins Ltd.

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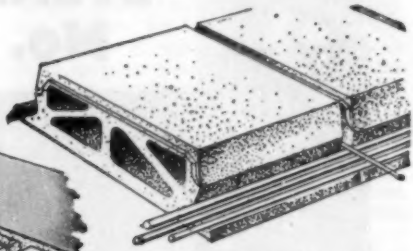
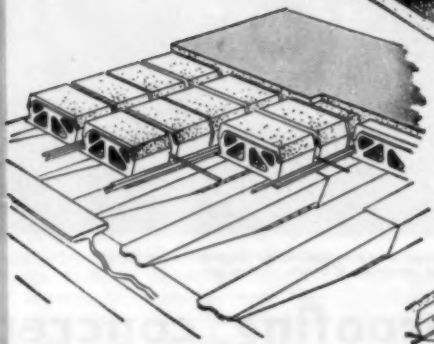
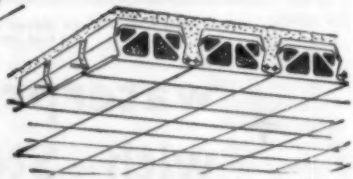


Smith's Two-Way Reinforced Floor for distribution of point loads with efficiency and economy.



Showing Two-Way Reinforcement and Hollow Concrete Blocks laid on Trianco Telescopic Centers.



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moisten the aggregates; in fact we rediscovered a truth that had been well known at least a hundred years ago. The consequent use of stiffer concrete led to the introduction of vibratory methods of consolidation.

Concrete cast in place was in the early days, and still remains, the most difficult and uncertain of all the processes of reinforced concrete construction to control and maintain at its highest possible standard. Fifty years ago some poor quality concrete was made as a result of the use of too much water, poor compaction, dirty aggregates, and unsuitable proportioning, and such failures as have occurred have been generally caused by the porosity of the concrete rather than by its lack of strength. It should, however, never be forgotten that most of the good qualities of concrete, such as resistance to weathering and abrasion, impermeability, and so on accompany high compressive strength. However, in spite of the lack of the knowledge and experience that we now possess, most reinforced concrete structures built early in the century were highly successful and many of them are still in use.

Applications of Concrete.

FLOORS.—Concrete was at first used mainly for floors in buildings, generally of the continuous cast-in-situ type supported on steel beams. Then, as confidence grew and its fire-resisting properties became appreciated, steel beams were replaced by reinforced concrete T-beams. Later, brick piers and steel stanchions tended to be replaced by reinforced concrete. Obsolescent by-laws for some time hindered both steel-frame and concrete-frame construction, particularly for exterior walls. When these were amended and steel-frame buildings became common, numerous patent floors were introduced, generally of a precast, rather deep, hollow, and fire and sound-resisting type, which, apart from low initial cost, were capable of considerable spans with little need for intermediate temporary propping. Frequently reinforced concrete frames were substituted for steel frames, and large buildings were constructed completely of reinforced concrete. Some of the best examples of such buildings are the large modern blocks of flats.

FOUNDATIONS. — As a foundation material concrete has been in use since ancient times, frequently in conjunction with timber piles. One of the earliest applications of reinforced concrete was in the form of precast square piles to replace timber piles. We now have the choice of driven piles of almost any length and of any required cross section, solid or hollow, in both reinforced and prestressed concrete, and also of systems of both driven and bored cast-in-place piles, the latter being particularly suitable where headroom is limited or where vibration would be objectionable. It is perhaps its application to piling that constitutes the most beneficial use to which reinforced concrete has been put and where its claims to permanence without maintenance costs may be most fully implemented. Timber piles are now seldom used and steel piles relatively rarely. Fifty years ago inclined piles were very unusual.

WATER-RETAINING STRUCTURES.—That the water-retaining properties of concrete, both plain and reinforced, were soon appreciated is shown by its early application to water towers and tanks. Many such structures are in use to-day after forty to fifty years of service. Static water of low head in contact with concrete acts as a preservative, and concrete kept continuously wet remains expanded; consequently well-designed water-retaining structures seldom leak or require expenditure for maintenance. More recently the advantages of prestressing have been adopted to produce crack-free concrete of very high quality in elevated tanks.

BRIDGES.—The application of reinforced concrete to bridges was less rapid. During the first decade of this century, construction in masonry was in full swing and masons were plentiful. Concrete, therefore, was little used for either precast work or for in-situ pier cappings and bed courses. Bedstones generally consisted of well-dressed stone, with a sheet of lead above as a bed to accommodate irregularities under the bearing-plates of steel beams. It was also during this period that in jack arches the concrete backing on brick arches was replaced by concrete laid directly on the timber shuttering, thus replacing rings of blue or brindle brick arching between parallel steel beams. Later the jack arches gave place to reinforced concrete slabs laid on the steel beams. This type of bridge

floor is quite common to-day, with the added economy effected by the incorporation of the steel cross girders or longitudinal stringers with the slab on a " tee-beam " principle. Also, under the bases of heavily-laden steel stanchions concrete was being substituted for strong brick pedestals which previously were used in considerable thickness for spreading the load on to the concrete foundation.

All through the ages bridges of one or more short spans were generally of the beam-and-post type in timber, a type suitable for replacement in reinforced concrete. Longer spans were generally arches of brick or masonry with some outstanding examples in cast iron of considerable span. This, again, is a type of construction for which reinforced concrete is very suitable either in the form of curved-slab spandrel-filled arches for small spans, or in the form of arched ribs or deep arched hollow slabs for moderate spans or even for spans of some hundreds of feet.

Types of design particularly suited to the monolithic properties of reinforced concrete were slow in coming. These types consist of " frame " bridges of one or more openings for small to moderate spans, and of continuous girders of variable moment of inertia for larger spans. Both of these types, with the soffit rising to the centre of the span, are economical of material and provide good headroom to traffic below.

With the advent of prestressed concrete it has become quite usual, particularly in railway work, to reconstruct decks in factory-made prestressed precast beams that can be erected as quickly as steel girders.

MARINE STRUCTURES.—In the early application of reinforced concrete to jetties, they were in the form of ribbed decks, resembling warehouse floors, supported on braced piling similar to old timber piers. Considerable trouble was experienced where porous concrete admitted the disintegrating and corrosive influences of sea-water or polluted water, resulting in disruption of the concrete and penetration to the reinforcement, as was apt to occur particularly in the exterior angles of beams supporting the floor and at times in the bracing.

Gradually changes in design were made by stabilising such structures against the horizontal forces experienced during the berthing of ships by means of additional raking piles, and this largely or wholly eliminated the need for bracing. Great improvements were also effected in the arrangement of the protective fendering by devices for absorbing the shock caused by impact when arresting the sideways motion of ships as they approach their berthing places. Also, decks of the beam-and-slab type were replaced by thick continuous slabs having soffits devoid of any projections where spray would lodge and its deposits cause cumulative disruption and corrosion. Round piles made by the spinning process have also been substituted for square piles, thus using concrete in its densest form and eliminating corners. With prestressing and precasting, dense concrete of highest quality is attainable having highly non-absorbent surfaces.

In recent years dock walls of the old gravity type have seldom been constructed. Arrangements of thick deck slabs on raking piles, frequently tied back to land-anchors, are now usual and result in great economy in cost and time of construction compared with the previous massive walls.

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SITUATIONS VACANT. Senior reinforced concrete designers wanted by leading reinforced concrete engineers and contractors. Must be fully conversant with Code of Practice, L.C.C. Bye-Laws, and able to design light-framed structures from estimating stage to final details. Five-days' week. Pension scheme. Progressive position. Starting salary from £900 upwards according to ability. This year's holiday arrangements honoured. Juniors also required, similar conditions. Write Box 4172, CONCRETE AND CONSTRUCTIONAL ENGINEERING, 14 Dartmouth Street, London, S.W.1.

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SITUATION VACANT. Birmingham district. Reinforced concrete designer required for specialist drawing office handling a wide variety of interesting structures. Five-days' week, pension scheme and staff canteen. Apply, giving details of experience, and salary required, to "TWISTEEL" REINFORCEMENT LIMITED, Alma Street, Smethwick, Staffs.

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SITUATION VACANT. Structural designer-draughtsman required by the design department of the engineering division. Should be experienced in the design of structures in reinforced concrete and structural steelwork, and the preparation of working drawings. Minimum qualifications: Higher National Certificate in Structural Engineering or equivalent. The position can be regarded as permanent and progressive. The company operates a non-contributory pension and insurance plan. Apply by letter to the PERSONNEL DEPARTMENT, KODAK, LTD. (Factories), Wealdstone, Middlesex.

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(*Continued on page ccxi.*)

MISCELLANEOUS ADVERTISEMENTS.

(Continued from page ccxix)

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Architects: Sir Percy Thomas & Son, Cardiff.
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Contractors: John Morgan (Builders) Ltd., Cardiff.

3 *B.B.C. Television Centre,* London, W.12.
Architects: Grsham Dawbarn Esq., C.B.E. Messrs. Norman & Dawburn, London, in association with M. T. Tudsbury, Esq., Consulting Civil Engineer to B.B.C.
Contractors: Higgs & Hill Ltd., G. Wimpey & Co. Ltd., London.

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This easily-handled pneumatic turbo-vibrator has a frequency range of 10,000 to 18,000 per minute. Its vibrating head, illustrated on the left, has been specially designed to eliminate maintenance costs. The head can be supplied in sizes from 1 $\frac{1}{16}$ in. diameter to 4 in. diameter, in lengths from 19½ in. to 24 in. This new type of vibrator represents an important step in the development of modern equipment for concrete work and will conform to all the requirements for the highest efficiency with the lowest operating costs.

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